

Bayesian Compressed Vector Autoregressions*

Gary Koop

University of Strathclyde[†]

Dimitris Korobilis

University of Essex[‡]

Davide Pettenuzzo

Brandeis University[§]

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Abstract

Macroeconomists are increasingly working with large Vector Autoregressions (VARs) where the number of parameters vastly exceeds the number of observations. Existing approaches either involve prior shrinkage or the use of factor methods. In this paper, we develop an alternative based on ideas from the compressed regression literature. It involves randomly compressing the explanatory variables prior to analysis. A huge dimensional problem is thus turned into a much smaller, more computationally tractable one. Bayesian model averaging can be done over various compressions, attaching greater weight to compressions which forecast well. In a macroeconomic application involving up to 129 variables, we find compressed VAR methods to forecast as well or better than either factor methods or large VAR methods involving prior shrinkage.

Keywords: multivariate time series, random projection, forecasting

JEL Classifications: C11, C32, C53

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[†]University of Strathclyde, Department of Economics, Room 4.06, Sir William Duncan Building, 130 Rottenrow, Glasgow G4 0GE, United Kingdom. gary.koop@strath.ac.uk

[‡]Essex Business School, Wivenhoe Park, Colchester, CO4 3SQ, United Kingdom. Dimitris.Korobilis@glasgow.ac.uk

[§]Brandeis University, Sachar International Center, 415 South St, Waltham, MA. dpettenu@brandeis.edu

1 Introduction

Vector autoregressions (VARs) have been an important tool in macroeconomics since the seminal work of Sims (1980). Recently, many researchers in macroeconomics and finance have been using large VARs involving dozens or hundreds of dependent variables (see, among many others, Banbura, Giannone and Reichlin, 2010, Carriero, Kapetanios and Marcellino, 2009, Koop, 2013, Koop and Korobilis, 2013, Korobilis, 2013, Giannone, Lenza, Momferatou and Onorante, 2014 and Gefang, 2014). Such models often have many more parameters than observations, over-fit the data in-sample, and, as a consequence, forecast poorly out-of-sample. Researchers working in the literature typically use prior shrinkage on the parameters to overcome such over-parametrization concerns. The Minnesota prior is particularly popular, but other approaches such as the LASSO (least absolute shrinkage and selection operator, see Park and Casella, 2008 and Gefang, 2014) and SSVS (stochastic search variable selection, see George, Sun and Ni, 2008) have also been used. Most flexible Bayesian priors that result in shrinkage of high-dimensional parameter spaces rely on computationally intensive Markov Chain Monte Carlo (MCMC) methods and their application to recursive forecasting exercises can, as a consequence, be prohibitive or even infeasible. The only exception is a variant of the Minnesota prior that is based on the natural conjugate prior, an idea that has recently been exploited by Banbura, Giannone and Reichlin (2010) and Giannone, Lenza and Primiceri (2015), among others. While this prior allows for an analytical formula for the posterior, there is a cost in terms of flexibility in that a priori all VAR equations are treated in the same manner; see Koop and Korobilis (2010) for a further discussion of this aspect of the natural conjugate prior.

The themes of wishing to work with Big Data¹ and needing empirically-sensible shrinkage of some kind also arise in the compressed regression literature; see Donoho (2006). In this literature, shrinkage is achieved by compressing the data instead of the parameters. These methods are used in a variety of models and fields (e.g. neuroimaging, molecular epidemiology, astronomy). A crucial aspect of these methods is that the projections used to compress

¹Big Data comes in two forms that are often called Tall and Fat. Tall data involves a huge number of observations, whereas Fat Data involves a huge number of variables. In this paper, we fall in the Fat Data part of the literature.

the data are drawn randomly in a data oblivious manner. That is, the projections do not involve the data and are thus computationally trivial. Recently, Guhaniyogi and Dunson (2015) introduced the idea of Bayesian Compressed regression, where a number of different projections are randomly generated and the explanatory variables are compressed accordingly. Next, Bayesian model averaging (BMA) methods are used to attach different weights to the projections based on the explanatory power the compressed variables have for the dependent variable.

In economics, alternative methods for compressing the data exist. The most popular of these is principal components (PC) as used, for instance, in the Factor-Augmented VAR, FAVAR, of Bernanke, Boivin and Elias (2005) or the dynamic factor model (DFM) of, e.g., Geweke (1977) and Stock and Watson (2002). PC methods compress the original data into a set of lower-dimensional factors which can then be exploited in a parsimonious econometric specification, for example, a univariate regression or a small VAR. The gains in computation from such an approach are large (but not as large as the data oblivious methods used in the compressed regression literature), since principal components are relatively easy to compute and under mild conditions provide consistent estimates of unobserved factors for a wide variety of models, including those with structural instabilities in coefficients (Bates, Plagborg-Møller, Stock and Watson, 2013). However, the data compression is done without reference to the dependent variable(s). PC is thus referred to as an unsupervised data compression method. In contrast, the approach of Guhaniyogi and Dunson (2015) to compressed regression, since it involves the use of BMA, is supervised. To our knowledge, supervised compressed regression methods of this sort have not yet been used in the VAR literature.²

In this paper, we extend the Bayesian random compression methods of Guhaniyogi and Dunson (2015), developed for the regression model, to the VAR leading to the Bayesian Compressed VAR (BCVAR). In doing so, we introduce several novel features. First, we generalize the compression schemes of Guhaniyogi and Dunson (2015) and apply them both to the VAR coefficients and the elements of the error covariance matrix. In high dimensional

²Carriero, Kapetanios and Marcellino (2016) use a reduced rank VAR framework they refer to as a multivariate autoregressive index model that shares similarities with the BCVAR used in this paper. However, they use computationally-burdensome MCMC methods which would preclude their use in very high dimensional models.

VARs, the error covariance matrix will likely contain a large number of unknown parameters. As a concrete example, the error covariance matrix of the largest VAR we consider in our empirical application includes more than 8,000 free parameters. Compressing the VAR coefficients while leaving these parameters unconstrained may still lead to a significant degree of over-parametrization and poor forecast performance, which explains our desire to compress the covariance matrix. Second, we allow the explanatory variables in the different equations of the VAR to be compressed in potentially different ways. To accomplish this, we develop a computationally efficient algorithm that breaks down the estimation of the high dimensional compressed VAR into the estimation of its individual equations. We believe this feature to be particularly important for macroeconomic VARs, where the first own lag in each equation is often found to have important explanatory power, and forcing the same (compressed) variables to appear in each equation seems therefore problematic. Our algorithm has very low requirements in terms of memory allocation and, since the VAR equations are assumed to be independent, can be easily parallelized to fully exploit the power of modern high-performance computer clusters (HPC).³ Third, we generalize our compressed VAR methods to the case of large-dimensional VARs with equation-specific time-varying parameters and volatilities. This is achieved by extending the approach developed in Koop and Korobilis (2013) to the compressed VAR, relying on variance discounting methods to model, in a computationally efficient way, the time variation in the VAR coefficients and error covariance matrix.

We carry out a substantial macroeconomic forecasting exercise involving VARs with up to 129 dependent variables and 13 lags. We compare the forecasting performance of seven key macroeconomic variables using the BCVAR to various popular alternatives: univariate AR models, the DFM, the FAVAR, and the Minnesota prior VAR. Our results are encouraging for the BCVAR, showing substantial forecast improvements in many cases and comparable forecast performance in the remainder.

The rest of the paper is organized as follows. Section 2 provides a description of the theory behind random compression. Section 3 introduces the Bayesian Compressed VAR with constant parameters, and develops methods for posterior and predictive analysis, while

³This work made use of the High Performance Computing Cluster (HPC64) at Brandeis University.

section 4 describes the empirical application. Section 5 introduces heteroskedasticity and time-variation in the parameters of the BCVAR and documents that these extensions further improve the forecasting performance of our approach. Section 6 provides some concluding remarks.

2 The Theory and Practice of Random Compression

Random compression methods have been used in fields such as machine learning and image recognition as a way of projecting the information in data sets with a huge number of variables into a much lower dimensional set of variables. In this way, they are similar to PC methods, which take as inputs many variables and produce as the output orthogonal factors. With PC methods, the first factor accounts for as much of the variability in the data as possible, the second factor the second most, etc. Typically, a few factors are enough to explain most of the variability in the data and, accordingly, parsimonious models involving only a few factors can be constructed. Random compression does something similar, but is computationally simpler, and capable of dealing with a massively huge number of variables. For instance, in a regression context, Guhaniyogi and Dunson (2015) have an application involving 84,363 explanatory variables.

To fix the basic ideas of random compression, let X be a $T \times k$ data matrix involving T observations on k variables where $k \gg T$. X_t is a $1 \times k$ vector denoting the t^{th} row of X . Define the projection matrix, Φ , which is $m \times k$ with $m \ll k$ and $\tilde{X}_t' = \Phi X_t'$. Then \tilde{X}_t is the $1 \times m$ vector denoting the t^{th} row of the compressed data matrix, \tilde{X} . Since \tilde{X} has m columns and X has k , the former is much smaller and is much easier to work with in the context of a statistical model such as a regression or a VAR. To see precisely how this works in a regression context, let y_t be the dependent variable and consider the regression:

$$y_t = X_t \beta + \varepsilon_t. \quad (1)$$

If $k \gg T$, then working directly with (1) is impossible with some statistical methods (e.g. maximum likelihood estimation) and computationally demanding with others (e.g. Bayesian approaches which require the use of MCMC methods). Some of the computational burden can arise simply due to the need to store in memory huge data matrices. Manipulating such data

matrices even a single time can be very demanding. For instance, calculation of the Bayesian posterior mean under a natural conjugate prior requires, among other manipulations, inversion of a $k \times k$ matrix involving the data. This can be difficult if k is huge. In order to deal with a large number of predictors, one can specify a compressed regression variant of (1)

$$y_t = (\Phi X_t')' \beta^c + \varepsilon_t. \quad (2)$$

Once the explanatory variables have been compressed (i.e. conditional on Φ), standard Bayesian regression methods can be used for the regression of y_t on \tilde{X}_t . If a natural conjugate prior is used, then analytical formulae exist for the posterior, marginal likelihood, and predictive density and computation is trivial. Note that the model in (2) has the same structure as a reduced-rank regression (early work in the econometrics literature includes Geweke, 1996 and Kleibergen and Van Dijk, 1998), as the k explanatory variables in the original regression model are squeezed into a small number of explanatory variables given by the vector $\tilde{X}_t = \Phi X_t'$. The crucial difference with likelihood-based approaches such as the ones proposed by Geweke (1996), Kleibergen and Van Dijk (1998) and Carriero, Kapetanios and Marcellino (2016) is that the matrix Φ is not estimated. This is the main idea behind compressed regression methods, which recommend treating Φ as a random matrix and drawing its elements in some fashion.⁴

The key question is: what information is lost by compressing the data in this fashion? The answer is that, under certain conditions, the loss of information may be small. The underlying motivation for random compression arises from the Johnson-Lindenstrauss lemma (see Johnson and Lindenstrauss, 1984). This states that any k point subset of Euclidean space can be embedded in $m = O(\log(k)/\epsilon^2)$ dimensions without distorting the distances between any pair of points by more than a factor of $1 \pm \epsilon$ for any $0 < \epsilon < 1$. In the econometrics literature, Ng (2016, pages 10-13) provides a detailed explanation and the intuition behind this rather remarkable result and shows how it can be used to tackle economic problems. Further intuition on the potential usefulness of these methods in the linear regression setting of (2) can be drawn from the literature on random subspace methods (see Boot and Nibbering,

⁴Random projection methods are referred to as *data oblivious*, since Φ is drawn without reference to the data. A key early paper in this literature is Achlioptas (2003), which provides theoretical justification for various ways of drawing Φ in a computationally-trivial manner.

2016), and complete subset regression (see Elliott, Gargano and Timmermann, 2013, 2015). Both these approaches are similar to the compressed regression in (2). In particular, random subspace methods involve randomly drawing subsets of the explanatory variables, while the complete subset regression method of Elliott, Gargano and Timmermann (2013, 2015) uses equal-weighted combinations of all available subsets of explanatory variables, and resorts to randomly selecting the subsets when the number of regressors is larger than the total number of observations available. Another important reference in this context is Guhaniyogi and Dunson (2015), who provide proofs of the theoretical properties of compressed regression methods, asymptotically in T and k . Under some weak assumptions, the most significant relating to sparsity (e.g. on how fast m can grow relative to k as the sample size increases), Guhaniyogi and Dunson (2015) show that their Bayesian compressed regression algorithm produces a predictive density which converges to the true predictive density. The convergence rate depends on how fast m and k grow with T . With some loose restrictions on this, they obtain near parametric rates of convergence to the true predictive density. In a simulation study and empirical work, they document excellent coverage properties of predictive intervals and large computational savings relative to popular alternatives. We note that in the large VAR there is likely to be a high degree of sparsity since most VAR coefficients are likely to be zero, especially for more distant lag lengths. In such a case, the theoretical results of Guhaniyogi and Dunson (2015) suggest fast convergence should occur and the computational benefits will likely be large.

Finally, note that Guhaniyogi and Dunson (2015) show that the desirable properties of random compression hold even for a single, data oblivious, random draw of Φ . In practice, they recommend taking many random draws and then averaging them. They draw Φ_{ij} , the ij^{th} element of Φ , (where $i = 1, \dots, m$ and $j = 1, \dots, k$) from the following distribution:

$$\begin{aligned} \Pr\left(\Phi_{ij} = \frac{1}{\sqrt{\varphi}}\right) &= \varphi^2 \\ \Pr\left(\Phi_{ij} = 0\right) &= 2(1 - \varphi)\varphi, \\ \Pr\left(\Phi_{ij} = -\frac{1}{\sqrt{\varphi}}\right) &= (1 - \varphi)^2 \end{aligned} \tag{3}$$

where φ and m are unknown parameters.⁵ Next, they rely on BMA to average across the different random projections entertained. Treating each $\Phi^{(r)}$ ($r = 1, \dots, R$) as defining a new

⁵The theory discussed above suggests that Φ should be a random matrix whose columns have unit lengths and, hence, Gram-Schmidt orthonormalization is done on the rows of the matrix Φ .

model, they first calculate the marginal likelihood for each model, and then average across the various models using weights proportional to their marginal likelihoods. Note also that m and φ can be estimated as part of this BMA exercise. In fact, Guhaniyogi and Dunson (2015) recommend simulating φ from the $U[a, b]$ distribution, where a (b) is set to a number slightly above zero (below one) to ensure numerical stability. As for m , they recommend simulating it from the $U[2 \log(k), \min(T, k)]$ distribution.

Intuitively, the use of BMA will ensure that bad compressions (i.e. those that lead to the loss of information important for explaining y_t) are avoided or down-weighted. To provide some more context, note that if we were to interpret m and φ and, thus, Φ , as random parameters (instead of specification choices defining a particular compressed regression), then BMA can be interpreted as importance sampling. That is, the Uniform distributions that Guhaniyogi and Dunson (2015) use for drawing φ and m , respectively, can be interpreted as importance functions. Importance sampling weights are proportional to the posterior for m and φ . But this is equivalent to the marginal likelihood which arises if Φ is interpreted as defining a model. Thus, in this particular setting, importance sampling is equivalent to BMA. In the same manner that importance sampling attaches more weight to draws from high regions of posterior probability, doing BMA with randomly compressed regressions attaches more weight to good draws of Φ which have high marginal likelihoods.

In a VAR context, doing BMA across models should only improve empirical performance since this will lead to more weight being attached to choices of Φ which are effective in explaining the dependent variables. Such supervised dimension reduction techniques contrast with unsupervised techniques such as PC. It is likely that supervised methods such as this will forecast better than unsupervised methods, a point we investigate in our empirical work.

In summary, for a given compression matrix, Φ , the huge dimensional data matrix is compressed into a much lower dimension. This compressed data matrix can then be used in a statistical model such as a regression or a VAR. The theoretical statistical literature on random compression has developed methods such as (3) for randomly drawing the compression matrix and showed them to have desirable properties under weak conditions which are likely to hold in large VARs. By averaging over different draws for Φ (which can differ both in terms of m and φ) BMA can be done. All this can be done in a computationally simple manner,

working only with models of low dimension.

3 Random Compression of VARs

We start with the standard reduced form VAR model,⁶

$$Y_t = BY_{t-1} + \epsilon_t \quad (4)$$

where Y_t for $t = 1, \dots, T$ is an $n \times 1$ vector containing observations on n time series variables, ϵ_t is i.i.d. $\mathcal{N}(0, \Omega)$ and B is an $n \times n$ matrix of coefficients. Note that, with $n = 100$, the uncompressed VAR will have 10,000 coefficients in B and 5,050 in Ω . In a VAR(13), such as the one used in this paper, the former number becomes 130,000. It is easy to see why computation can become daunting in large VARs and why there is a need for shrinkage.

To compress the explanatory variables in the VAR, we can use the matrix Φ given in (3) but now it will be an $m \times n$ matrix where $m \ll n$, subject to the normalization $\Phi'\Phi = I$. In a similar fashion to (2), we can define the compressed VAR:

$$Y_t = B^c(\Phi Y_{t-1}) + \epsilon_t, \quad (5)$$

where B^c is $m \times n$. Thus, we can draw upon the motivations and theorems of, e.g., Guhaniyogi and Dunson (2015) to offer theoretical backing for the compressed VAR. If a natural conjugate prior is used, for a given draw of Φ the posterior, marginal likelihood, and predictive density of the compressed VAR in (5) have familiar analytical forms (see, e.g., Koop and Korobilis, 2009). These, along with a method for drawing Φ , is all that are required to forecast with the BCVAR. And, if m is small, the necessary computations of the natural conjugate BCVAR are straightforward.⁷

We note however that the natural conjugate prior has some well-known restrictive properties in VARs.⁸ In the context of the compressed VAR, working with a Φ of dimension

⁶For notational simplicity, we explain our methods using a VAR(1) with no deterministic terms. These can be added in a straightforward fashion. In our empirical work, we have monthly data and use 13 lags and an intercept.

⁷In the literature on compression in multivariate regression, it is worth citing Hoff (2007). This paper uses BMA to estimate the rank of a singular value decomposition for the right-hand side variables in a class of models which includes the VAR. In contrast to our approach, he uses Gibbs sampling methods to estimate the optimal decomposition.

⁸These are summarized on pages 279-280 of Koop and Korobilis (2009).

$m \times n$ as defined in (5), with only n columns instead of n^2 would likely be much too restrictive in many empirical contexts. For instance, it would imply that to delete a variable in one equation, then that same variable would have to be deleted from all equations. In macroeconomic VARs, where the first own lag in each equation is often found to have important explanatory power, such a property seems problematic. It would imply, say, that lagged inflation could either be included in every equation or none when what we might really want is for lagged inflation to be included in the inflation equation but not most of the other equations in the VAR.⁹

An additional issue with the natural conjugate BCVAR is that it allows the error covariance matrix to be unrestricted. In high dimensional VARs, Ω contains a large number of parameters and we may want a method which allows for their compression. This issue does not arise in the regression model of Guhaniyogi and Dunson (2015) but is potentially very important in large VARs. For example, in our application the largest VAR we estimate has an error covariance matrix containing 8,385 unknown parameters. These considerations motivate working with a re-parametrized version of the BCVAR that allows for compression of the error covariance matrix. Following common practice (see, e.g., Primiceri, 2005, Eisenstat, Chan and Strachan, 2015 and Carriero, Clark and Marcellino, 2015) we use a triangular decomposition of Ω :

$$A\Omega A' = \Sigma\Sigma, \quad (6)$$

where Σ is a diagonal matrix with diagonal elements σ_i ($i = 1, \dots, n$), and A is a lower triangular matrix with ones on the main diagonal. Next, we rewrite $A = I_n + \tilde{A}$, where I_n is the $(n \times n)$ identity matrix and \tilde{A} is a lower triangular matrix with zeros on the main diagonal. Using this notation, we can rewrite the reduced-form VAR in (4) as follows

$$Y_t = BY_{t-1} + A^{-1}\Sigma E_t \quad (7)$$

where $E_t \sim N(0, I_n)$. Further rearranging, we have

$$\begin{aligned} Y_t &= \Gamma Y_{t-1} + \tilde{A}(-Y_t) + \Sigma E_t \\ &= \Theta Z_t + \Sigma E_t \end{aligned} \quad (8)$$

⁹An alternative compressed VAR approach would involve multiplying both sides of the equation by Φ , thus compressing the dependent variables as well. In order to forecast, say, the first n_f variables the upper left hand $n_f \times n_f$ block of Φ could be set to the identity matrix. Such an approach would be similar in spirit to a factor-augmented VAR but with the factors being replaced by random compressions.

where $Z_t = [Y'_{t-1}, -Y'_t]'$, $\Gamma = AB$ and $\Theta = [\Gamma, \tilde{A}]$. Because of the lower triangular structure of \tilde{A} , the first equation of the VAR above includes only Y_{t-1} as explanatory variables, the second equation includes $(Y'_{t-1}, -Y_{1,t})'$, the third equation includes $(Y'_{t-1}, -Y_{1,t}, -Y_{2,t})'$, and so on (here $Y_{i,t}$ denotes the i -th element of the vector Y_t). Note that this lower triangular structure, along with the diagonality of Σ , means that equation-by-equation estimation of the VAR can be done, a fact we exploit in our algorithm. Furthermore, since the elements of \tilde{A} control the error covariances, by compressing the model in (8) we can compress the error covariances as well as the reduced form VAR coefficients.

Given that in the triangular specification of the VAR each equation has a different number of explanatory variables, a natural way of applying compression in (8) is through the following specification:

$$Y_{i,t} = \Theta_i^c (\Phi_i Z_t^i) + \sigma_i E_{i,t} \quad i = 1, \dots, n \quad (9)$$

where now Z_t^i denotes the subset of the vector Z_t which applies to the i -th equation of the VAR: $Z_t^1 = (Y_{t-1})$, $Z_t^2 = (Y'_{t-1}, -Y_{1,t})'$, $Z_t^3 = (Y'_{t-1}, -Y_{1,t}, -Y_{2,t})'$, and so on. Similarly, Φ_i is a matrix with m rows and column dimension that conforms with Z_t^i . Following (9), we now have n compression matrices (each of potentially different dimension and with different randomly drawn elements), and as a result the explanatory variables in the equations of the original VAR can be compressed in different ways. Note also that an alternative way to estimate a compressed VAR version of model (8) would be to write the model in its SUR form; see Koop and Korobilis (2009). If we did so, the data matrix Z_t would have to be expanded by taking its Kronecker product with I_n . For large n such an approach would require huge amounts of memory (many times more than a modern personal computer has available). Even if we were to use sparse matrix calculations, having to define the non-zero elements of the matrices in the SUR form of a large VAR would result in very slow computation. On the other hand, the equation-by-equation estimation we propose in (9) is simpler and can be easily parallelizable, since the VAR equations are transformed so as to be independent.

For a given set of posterior draws of Θ_i^c and σ_i ($i = 1, \dots, n$), estimation and prediction can be done in a computationally-fast fashion using a variety of methods since each model will be of low dimension and, for the reasons discussed previously, all these can be done one

equation at a time. In the empirical work in this paper, we use standard Bayesian methods suggested in Zellner (1971) for the seemingly unrelated regressions model. In particular, for each equation we use the prior:

$$\begin{aligned}\Theta_i^c | \sigma_i^2 &\sim N(\underline{\Theta}_i^c, \sigma_i^2 \underline{V}_i) \\ \sigma_i^{-2} &\sim G(\underline{s}_i^{-2}, \underline{\nu}_i),\end{aligned}\tag{10}$$

where $G(\underline{s}_i^{-2}, \underline{\nu}_i)$ denotes the Gamma distribution with mean \underline{s}_i^{-2} and degrees of freedom $\underline{\nu}_i$. In our empirical work, we set $\underline{\Theta}_i^c = 0$, $\underline{V}_i = 0.5 \times I$ and, for σ_i^{-2} use the non-informative version of the prior (i.e. $\underline{\nu}_i = 0$). We then use familiar Bayesian results for the Normal linear regression model (e.g. Koop, 2003, page 37) to obtain analytical posteriors for both Θ_i^c and σ_i . The one-step ahead predictive density is also available analytically. However, h -step ahead predictive densities for $h > 1$ are not available analytically.¹⁰ To compute them, we proceed by first converting the estimated compressed triangular VAR in equation (9) back into the triangular VAR of equation (8), noting that

$$\Theta = [(\Theta_1^c \Phi_1, \mathbf{0}_n)', (\Theta_2^c \Phi_2, \mathbf{0}_{n-1})', \dots, (\Theta_{n-1}^c \Phi_{n-1}, 0)', (\Theta_n^c \Phi_n)']'\tag{11}$$

where $\mathbf{0}_n$ is an $(1 \times n)$ vector of zeros, $\mathbf{0}_{n-1}$ is an $(1 \times n - 1)$ vector of zeros, and so on. Subsequently, we go from the triangular VAR in equation (8) to the original reduced-form VAR in equation (4) by noting that $B = A^{-1}\Gamma$, where Γ can be recovered from the first $n \times n$ block of Θ in (11), and A is constructed from \tilde{A} using the remaining elements of Θ (see equation (8)). Finally, the covariance matrix of the reduced form VAR is simply given by equation (6), where both A and Σ are known. After these transformations are implemented, standard results for Bayesian VARs can be used to obtain multi-step-ahead density forecasts.

So far we have discussed specification and estimation of the compressed VAR conditional on a single compression Φ (or Φ_i , $i = 1, \dots, n$). In practice, we generate R sets of such compression matrices $\Phi_i^{(r)}$ ($i = 1, \dots, n$ and $r = 1, \dots, R$), and estimate an equal number of compressed VAR models, which we denote with M_1, \dots, M_R . Then, for each model, we use the predictive simulation methods described above to obtain the full predictive density

¹⁰Point forecasts can be iterated forward in the usual fashion, but predictive simulation is required to produce h -step ahead predictive densities.

$p(Y_{t+h}|M_r, \mathcal{D}^t)$, where $h = 1, \dots, H$. For each forecast horizon h , the final BMA forecast is a mixture of the form

$$p(Y_{t+h}|\mathcal{D}^t) = \sum_{r=1}^R w_r p(Y_{t+h}|M_r, \mathcal{D}^t), \quad (12)$$

where \mathcal{D}^t is the information set available at time t , $w_r = \exp(-.5\Psi_r) / \sum_{r=1}^R \exp(-.5\Psi_r)$ is model M_r weight, and $\Psi_r = BIC_r - BIC_{\min}$, with BIC_r being the value of the Bayesian Information Criterion (BIC) of model M_r and BIC_{\min} the minimum value of the BIC among all R models. We use BIC to approximate the marginal likelihood because it can be computed easily for high-dimensional VARs and is insensitive to the choice of the priors.

In our empirical work, the $\Phi_i^{(r)}$'s are randomly drawn using the strategy described in (3). This scheme means that for each of the R random compression matrices, we have to generate the parameter φ and decide on the number of rows m of each $\Phi_i^{(r)}$ (that is, the dimension of the projected space). Both these parameters are drawn randomly: φ is drawn from the uniform $U[0.1, 0.8]$ distribution and m is drawn from the discrete $U[1, 5 \ln(k_i)]$, where k_i is the number of explanatory variables included in Z_t^i for VAR equation i .¹¹

We note, to conclude this section, that papers such as Achlioptas (2003) have proposed alternative schemes to the one we adopted in (3) to randomly draw the elements of Φ_i . While some of these may be potentially more efficient and can provide a higher degree of sparsity (zeros in Φ_i), in our macroeconomic application we found that a wide range of alternative random projection schemes produced almost identical forecasts. Thus, in our empirical application we will focus exclusively on the scheme proposed by Guhaniyogi and Dunson (2015), as described in equation (3).

4 Empirical Application: Macroeconomic Forecasting with Large VARs

This section introduces the macroeconomic data considered in our application and reports the forecasting performance of the Bayesian Compressed VAR methods described in section 3, relative to a number of popular alternatives. We first consider the accuracy of point forecasts,

¹¹These choices are similar to those used in Guhaniyogi and Dunson (2015), but our choice to draw values of m as low as one is lower than theirs. We do this just to see if extreme compressions, which basically remove all the right-hand side variables, receive any support. Due to numerical stability reasons, for φ we do not consider the full support $[0, 1]$.

using Mean Squared Forecast Errors (MSFEs). Next, we turn to the quality of the density forecasts, and for that rely on the average of the log predictive likelihoods (ALPL), as in Geweke and Amisano (2010).

4.1 Data

We use the FRED-MD data-base of monthly US variables from January 1960 through December 2014. The reader is referred to McCracken and Ng (2015) for a description of this macroeconomic data set, which includes a range of variables from a broad range of categories (e.g. output, capacity, employment and unemployment, prices, wages, housing, inventories and orders, stock prices, interest rates, exchange rates and monetary aggregates). We use the 129 variables for which complete data was available, after transforming all variables using the transformation codes provided in [Appendix A](#).¹² We present detailed forecasting results for seven variables of interest: industrial production growth (INDPRO), the unemployment rate (UNRATE), total nonfarm employment (PAYEMS), the change in the Fed funds rate (FEDFUNDS), the change in the 10 year T-bill rate (GS10), the finished good producer price inflation (PPIFGS) and consumer price inflation (CPIAUCSL).¹³ In particular, we estimate VARs of different dimensions, with these seven variables included in all of our specifications. We have a Medium VAR with 19 variables, a Large VAR with 46 variables and a Huge VAR with all 129 variables.¹⁴ A listing of all variables (including which appear in which VAR) is given in [Appendix A](#). Note that most of our variables have substantial persistence in them and, accordingly, the first own lag in each equation almost always has important explanatory power. Accordingly, we do not compress the first own lag. This is included in every equation, with compression being done on the remaining

¹²In addition to dropping a few series with missing observations, we also remove the series non-borrowed reserves, as it became extremely volatile during the Great Recession.

¹³We also standardize our variables prior to estimation and forecasting. The forecasts of the original variables are then computed by inverting the transformation and reassigning means and variances. This standardization is computed recursively, i.e., using only the data that would have been available at each point in time to estimate the various models.

¹⁴Our terminology Medium, Large and Huge for VARs of dimension 19, 46 and 129, respectively is slightly non-standard. The original Banbura, Giannone and Reichlin (2010) medium VAR had 20 variables and their large VAR had 131 variables. In contrast, the large VARs of, e.g., Chan (2015) and Carriero, Clark and Marcellino (2016b) used for forecasting have only about 20 variables. In general, the emerging literature on larger VARs is working with VARs in this range (e.g. between 20 and 130 variables). We wish to investigate the use of random compression methods for VARs of a variety of dimensions within this range and feel our terminological choices capture this.

variables.¹⁵ Following Banbura et al. (2010), we choose a relatively large value for lag length ($p = 13$) for all the methods we compare, trusting in the compression or shrinkage of the various methods to remove unnecessary lags.

4.2 Estimating the Bayesian Compressed VAR

Random compression methods are most useful for forecasting and, hence, we will not discuss estimation of the model’s parameters in any detail. However, before turning to forecasting, it is worth presenting evidence relating to the random compression itself. This is controlled by m and φ , which define the dimension and the degree of sparsity in the compression matrix. [Figure 1](#) and [Figure 2](#) plot their empirical distributions for the Bayesian compressed VARs of different dimensions. They can be interpreted as approximations to the posteriors of these parameters. To aid in interpretation note that, in our compressed VARs, there is a different compression matrix in each equation and so, for brevity, the figures average over all equations and are based on the 75% of draws with highest posterior probability. Remember that smaller values of m indicate a higher degree of compression and, for a given m , $\varphi = 0.5$ induces the highest degree of sparsity.

The posteriors in the figures are clustered around sensible values. The high dimensional data vectors, Z_t^i , tend to be compressed down to dimensions of 10-20. The value of m tends to rise somewhat as we move from the Medium to Large to Huge VAR, but even for the latter almost all the posterior weight is clustered below 20. It is also worth noting that, even though we are drawing values of m as low as 1, such draws never receive appreciable weight. In other words, our algorithm is not attaching much weight to extreme compressions which reduce the high-dimensional vector of predictors too much. The posterior for φ tends to be clustered near the value which induces most sparsity.

4.3 Alternative Methods for Large VARs

We use the Bayesian compressed VAR methods introduced in [section 3](#) in two ways: the first one, which we label as BCVAR_c, compresses both the VAR coefficients and the error

¹⁵To be precise, we are always allowing the diagonal elements of Γ in (8) to be non-zero. We experimented with the alternative triangularization of [Carriero, Clark and Marcellino \(2016b\)](#) which allows for the diagonal elements of B in (4) to always be non-zero. These two approaches yielded very similar results, both in terms of treatment of first own lags and in forecast performance.

covariances as in (9). The second one, which we label BCVAR, is the same, except for the fact that it does not compress the error covariances.

To better assess the forecasting accuracy of these compressed VAR methods, we compare their performances against a number of popular alternatives. Reasoning that previous work with large numbers of dependent variables have typically used factor methods or large Bayesian VARs, we focus on these. In addition, we compare the forecasts using all of these methods to a benchmark approach which uses OLS forecasts from univariate AR(1) models.

Dynamic Factor Model

The dynamic factor model (DFM) can be written as:

$$\begin{aligned} Y_t &= \lambda_0 + \lambda_1 F_t + \epsilon_t \\ F_t &= \Phi_1 F_{t-1} + \dots + \Phi_p F_{t-p} + \epsilon_t^F \end{aligned} \tag{13}$$

where F_t is a $q \times 1$ vector factors (with $q \ll n$) which contains information extracted from all n variables, λ_0 and λ_1 are $n \times 1$ and $n \times q$ matrices, and $\epsilon_t \sim \mathcal{N}(0, \Sigma^Y)$ where Σ^Y is a diagonal matrix. The vector of factors is assumed to follow a VAR(p) process with $\epsilon_t^F \sim \mathcal{N}(0, \Sigma^F)$, with ϵ_t independent of ϵ_s^F at all t and s . We use principal component methods to estimate the factors.¹⁶

We select the number of factors q and the lag length p as follows: We specify the maximum number of factors and lag lengths to be $q^{\max} = \sqrt{n}$ and $p^{\max} = 13$, respectively. Next, at each point in time we use *BIC* to choose the optimal lag length and number of factors. We use Bayesian methods with non-informative priors to estimate and forecast with this model (note that the law of motion for the common factors in equation (13) is needed to iterate forward the forecasts when $h > 1$).

Factor-Augmented VAR

We use the Factor-Augmented VAR (FAVAR) of Bernanke, Boivin, Elias (2005) dividing Y_t into a set of primary variables of interest, Y_t^* (these are the same key seven variables listed

¹⁶Alternative estimators such as the quasi-maximum likelihood estimator of Doz, Giannone and Reichlin (2012) are possible. These authors note that principal components, quasi maximum likelihood and a two-step estimator based on Kalman smoother, all give basically the same results for $n > 25$ and $T > 50$. We use principal components for simplicity.

above), and the remainder \tilde{Y}_t , and work with the model:

$$\begin{aligned}\tilde{Y}_t &= \Lambda F_t + \epsilon_t^{\tilde{Y}} \\ \begin{bmatrix} F_t \\ Y_t^* \end{bmatrix} &= B_0 + B_1 \begin{bmatrix} F_{t-1} \\ Y_{t-1}^* \end{bmatrix} + \dots + B_p \begin{bmatrix} F_{t-p} \\ Y_{t-p}^* \end{bmatrix} + \epsilon_t^*.\end{aligned}\tag{14}$$

The vector $(F_t', Y_t^{*'})'$ is assumed to follow a VAR(p) process with $\epsilon_t^{\tilde{Y}} \sim \mathcal{N}(0, \Sigma^{\tilde{Y}})$, $\epsilon_t^* \sim \mathcal{N}(0, \Sigma^*)$, and ϵ_t independent of ϵ_s^* at all t and s . As with the DFM model, we rely on principal component methods to extract the factors F_t , and select the optimal number of factors q and the lag length p using *BIC*. We use Bayesian methods with non-informative priors to forecast with this model.

Bayesian VAR using the Minnesota Prior

We follow closely Banbura et al (2010)'s implementation of the Minnesota prior VAR which involves a single prior shrinkage parameter, ω . However, we select ω in a different manner than Banbura et al (2010), and estimate it in a data-based fashion similar to Giannone, Lenza and Primiceri (2015). We choose a grid of values for the inverse of the shrinkage factor ω^{-1} ranging from $0.5 \times \sqrt{np}$ to $10 \times \sqrt{np}$, in increments of $0.1 \times \sqrt{np}$. At each point in time, we use *BIC* to choose the optimal degree of shrinkage. All remaining specification and forecasting choices are exactly the same as in Banbura et al (2010) and, hence, are not reported here. In our empirical results, we use the acronym BVAR to refer to this approach.

To conclude this section, we would like to stress that we are only comparing our methods to alternatives that are computationally feasible with large VARs. This rules out many popular VAR-based approaches and explains why we are only considering the Minnesota prior VAR. But we note that even the Minnesota prior VAR will not handle the truly enormous VARs that may arise for the researcher working with multi-country data sets or combining macroeconomic and financial data. Random compression methods should scale up to handle VARs with thousands of variables (as will principal components methods), but the Minnesota prior VAR will not. Carriero, Clark and Marcellino (2016a) explore in detail the computational challenges of working with large VARs, and note that the posterior covariance matrix for the VAR is an $(np + 1)n$ matrix and manipulating this is the chief computational bottleneck. With general approaches (which do not involve a natural conjugate or Minnesota prior) manipulating such a matrix involves $O(n^6 p^3)$ operations, but with priors adopting a particular Kronecker structure

(e.g. the Minnesota prior) this can be reduced to $O(n^3p^3)$. This is a huge computational reduction when $n = 100$ which explains why so many large VAR researchers use priors which have this Kronecker structure (despite well known criticisms of it). But when $n = 1000$ or $n = 10,000$ even if the Kronecker structure is maintained there will come a point where computation will break down. Furthermore, when forecasting with large VARs the Minnesota prior is mainly used for point forecasting since obtaining the predictive density typically involves predictive simulation. This involves repeatedly simulating VAR coefficients and then simulating future values of the variables. This raises additional computational bottlenecks which limits the use of the Minnesota prior VAR in very large models.

4.4 Measures of Predictive Accuracy

We use the first half of the sample, January 1960–June 1987, to obtain initial parameter estimates for all models, which are then used to predict outcomes from July 1987 ($h = 1$) to June 1987 ($h = 12$). The next period, we include data for July 1987 in the estimation sample, and use the resulting estimates to predict the outcomes from August 1987 to July 1988. We proceed recursively in this fashion until December 2014, thus generating a time series of forecasts for each forecast horizon h , with $h = 1, \dots, 12$. Note that when $h > 1$, point forecasts are iterated and predictive simulation is used to produce the predictive densities.

Next, for each of the seven key variables listed above we summarize the precision of the h -step-ahead point forecasts for model i , relative to that from the univariate AR(1), by means of the ratio of MSFEs:

$$MSFE_{ijh} = \frac{\sum_{\tau=\underline{t}}^{\bar{t}-h} e_{i,j,\tau+h}^2}{\sum_{\tau=\underline{t}}^{\bar{t}-h} e_{bck,j,\tau+h}^2}, \quad (15)$$

where \underline{t} and \bar{t} denote the start and end of the out-of-sample period, and where $e_{i,j,\tau+h}^2$ and $e_{bck,j,\tau+h}^2$ are the squared forecast errors of variable j at time τ and forecast horizon h associated with model i ($i \in \{DFM, FAVAR, BVAR, BCVAR, BCVAR_c\}$) and the AR(1) model, respectively. The point forecasts used to compute the forecast errors are obtained by averaging over the draws from the various models' h -step-ahead predictive densities. Values of $MSFE_{ijh}$ below one suggest that model i produces more accurate point forecasts than the AR(1) benchmark for variable j and forecast horizon h .

We also assess the accuracy of the point forecasts of the various methods using the

multivariate loss function of Christoffersen and Diebold (1998). Specifically, we compute the ratio between the multivariate weighted mean squared forecast error (WMSFE) of model i and the WMSFE of the benchmark AR(1) model as follows:

$$WMSFE_{ih} = \frac{\sum_{\tau=\underline{t}}^{\bar{t}-h} we_{i,\tau+h}}{\sum_{\tau=\underline{t}}^{\bar{t}-h} we_{bcmk,\tau+h}}, \quad (16)$$

where $we_{i,\tau+h} = (e'_{i,\tau+h} \times W \times e_{i,\tau+h})$ and $we_{bcmk,\tau+h} = (e'_{bcmk,\tau+h} \times W \times e_{bcmk,\tau+h})$ are time $\tau+h$ weighted forecast errors of model i and the benchmark model, $e_{i,\tau+h}$ and $e_{bcmk,\tau+h}$ are the (7×1) vector of forecast errors for the key series we focus on, and W is an (7×7) matrix of weights. Following Carriero, Kapetanios and Marcellino (2011), we set the matrix W to be a diagonal matrix featuring on the diagonal the inverse of the variances of the series to be forecast.

As for the quality of the density forecasts, we follow Geweke and Amisano (2010) and compute the average log predictive likelihood differential between model i and the AR(1) benchmark,

$$ALPL_{ijh} = \frac{1}{\bar{t} - \underline{t} - h + 1} \sum_{\tau=\underline{t}}^{\bar{t}-h} (LPL_{i,j,\tau+h} - LPL_{bcmk,j,\tau+h}), \quad (17)$$

where $LPL_{i,j,\tau+h}$ ($LPL_{bcmk,j,\tau+h}$) denotes model i 's (benchmark's) log predictive score of variable j , computed at time $\tau+h$, i.e., the log of the h -step-ahead predictive density evaluated at the outcome. Positive values of $ALPL_{ijh}$ indicate that for variable j and forecast horizon h on average model i produces more accurate density forecasts than the benchmark model.

Finally, we consider the multivariate average log predictive likelihood differentials between model i and the benchmark AR(1),

$$MVALPL_{ih} = \frac{1}{\bar{t} - \underline{t} - h + 1} \sum_{\tau=\underline{t}}^{\bar{t}-h} (MVLPL_{i,\tau+h} - MVLPL_{bcmk,\tau+h}), \quad (18)$$

where $MVLPL_{i,\tau+h}$ and $MVLPL_{bcmk,\tau+h}$ denote the multivariate log predictive likelihoods of model i and the benchmark model at time $\tau+h$, computed under the assumption of joint normality.

In order to test the statistical significance of differences in point and density forecasts, we consider pairwise tests of equal predictive accuracy (henceforth, EPA; Diebold and Mariano, 1995; West, 1996) in terms of MSFE, WMSFE, ALPL, and MVALPL. All EPA tests we

conduct are based on a two sided test with the null hypothesis being the AR(1) benchmark. We use standard normal critical values. Based on simulation evidence in Clark and McCracken (2013), when computing the variance estimator which enters the test statistic we rely on Newey and West (1987) standard errors, with truncation at lag $h - 1$, and incorporate the finite sample correction due to Harvey et al. (1997). In the tables, we use ***, ** and * to denote results which are significant at the 1%, 5% and 10% levels, respectively, in favor of the model listed at the top of each column.

4.5 Forecasting Results

Tables 1 through 3 and the left side of Table 7 present evidence on the quality of our point forecasts for our seven main variables of interest relative to the AR(1) benchmark. With a few exceptions we are finding that BCVARs beat the benchmark and often tend to forecast better than the other approaches. This holds, with several exceptions, for every VAR dimension, variable and forecast horizon. Table 7, which presents the WMSFEs over the seven variables of interest, provides the best overall summary of our results as they relate to point forecasts. With six forecast horizons and three VAR dimensions, this table contains 18 dimensions in which point forecasts can be compared. In 17 of these, either BCVAR or BCVAR_c is the model with the lowest MSFE. In 12 of these cases, compressed VAR approaches beat the benchmark in a statistically significant manner. The FAVAR is the next best approach, although it is worth noting that in some cases (e.g. with short term forecasting and particularly with the medium VAR) it does poorly, failing to beat the AR(1) benchmark. Overall, we are finding random compression to work well, often the best but, in cases where it is not the best, it is not too far from the best so that a risk averse user might feel confident using random compression methods.

Thus, random compression of the VAR coefficients is at least competitive with other multivariate forecasting methods with the data set under consideration. Evidence relating to compression of the error covariance is more mixed. That is, in some instances the BCVAR_c forecasts better than the BCVAR, but there are many cases where the forecasts from the BCVAR model are more accurate.

With regards to forecast horizon, no clear pattern emerges. There is a slight tendency

for compressed VAR approaches to do particularly well at shorter horizons, but there are no strong differences across horizons. In terms of the individual variables, one notable pattern in these tables is that BCVAR and BCVAR_c are (with some exceptions) forecasting particularly well for the most important macroeconomic aggregates such as prices, unemployment and industrial production. In contrast, for the long-term interest rate (GS10), our Huge or Large VAR methods are almost never beating the benchmark. But at least in this case, where small models are forecasting well, it is reassuring to see that MSFEs obtained using random compression methods are only slightly worse than the benchmark ones. This indicates that random compression methods are finding that the GS10 equation in the Huge VAR is hugely over-parametrized, but is successfully compressing the explanatory variables so as obtain results that are nearly the same as those from parsimonious univariate models.

Figures 3 through 5 present evidence on when the forecasting gains of BCVARs relative to the other approaches are achieved. These plot the cumulative sum of weighted forecasting errors (jointly for the $N = 7$ variables of interest) for the benchmark AR(1) model minus those for a competing approach, $CSWFED_{iht} = \sum_{\tau=\underline{t}}^{t-h} (we_{bcmk, \tau+h} - we_{i, \tau+h})$, for different sized VAR sizes and different forecasting horizons. Positive values for this metric imply that an approach is beating the benchmark. For short horizons, BCVAR is the only approach that consistently beats the benchmark model, throughout the whole forecast period. All other approaches accumulate more forecast errors over time compared to the simple AR(1). It is particularly interesting that during the 2007-2009 crisis all multivariate methods seem to, at least temporarily, improve over the univariate AR(1). However, towards the end of the crisis, for all methods but the BCVAR relative forecast performance deteriorates abruptly. For longer forecast horizons some of the alternative multivariate models perform fairly well (e.g., at $h = 12$, the FAVAR ends up being the best model by a short margin). Nevertheless, even at these horizons BCVAR remains consistently a reliable forecasting model.¹⁷

Tables 4 through 6 and the right hand side of Table 7 shed light on the quality of our density forecasts by presenting averages of log predictive likelihoods for the VARs of different dimensions. Results are similar as for MSFEs and we will not discuss them in detail. But they

¹⁷Figure A.1 through A.6 in the online Appendix plot the cumulative sum of squared forecast error differentials individually for the seven series we focus on.

do differ in their strength in two ways. First, the evidence that compressed VAR approaches can beat univariate benchmarks becomes much more strong. See in particular the right hand side of [Table 7](#) which shows strong rejection of the hypothesis of EPA at every horizon and for every VAR dimension. Second, the evidence that compressed VARs can forecast better than BVAR or FAVAR approaches becomes somewhat weaker. In particular, with the medium and large VARs standard large Bayesian VAR methods using the Minnesota prior tend to forecast slightly better than the compressed VAR approaches. On the other hand, our BCVAR does particularly well in the Huge VAR case, improving over the standard large Bayesian VAR and FAVAR methods at all forecast horizons.

Figures [6](#), [7](#) and [8](#) plot the cumulative sums of the multivariate log predictive likelihood differentials, $CSMVLPD_{ij} = \sum_{\tau=\underline{t}}^{\bar{t}-h} (MVLPL_{i,\tau+h} - MVLPL_{bcmk,\tau+h})$, for VARs of different dimensions and across a number of forecast horizons. It is interesting to note that, in contrast to Figures [3](#) through [5](#), there is not strong evidence of a large deterioration in forecasting performance relative to the univariate benchmark. In general, our compressed VAR approaches may not be best in every case, but even when they are not they are close to the best.¹⁸

The preceding results compared the forecasting performance of various approaches to the AR(1) benchmark. Tables such as [Table 7](#) typically show strong evidence of statistically significant improvements of all the multivariate forecasting methods relative to this benchmark. To shed light on whether there are statistical significance differences between the multivariate approaches, [Table 8](#) presents forecast performance using the BVAR as the benchmark. If we use log predictive likelihoods as the measure of forecast performance, it can be seen that, although the compressed VAR approaches do better than the BVAR, this difference is not statistically significant. In fact, there are not statistically significant differences between any of our multivariate forecasting methods. When using MSFEs to evaluate forecast performance there are, however, some cases where the compressed VARs are forecasting significantly better than the Minnesota prior BVAR.

Finally, it is worth stressing that this section is simply comparing the forecast performance

¹⁸Figure A.7 through A.12 in the online Appendix plot the cumulative sum of log predictive likelihood differentials individually for the seven series we focus on.

of different plausible methods for a particular data set. However, the decision whether to use compression methods should not be based solely on this forecasting comparison. In other, larger applications, plausible alternatives to random compression such as the Minnesota prior BVAR or any VAR approach which requires the use of MCMC methods, may simply be computationally infeasible. The results presented in this section show that with the present data set, random compression works fairly well. With larger data sets, it may very well be that BCVAR is the only approach that is computationally feasible.

4.6 Robustness Checks

In the preceding sub-sections, we have shown that two particular ways of implementing compression methods with VARs produce forecasts which are as good or better than more computationally demanding alternatives. But there are many alternative ways of doing random compression that we have experimented with. As noted previously a logical (and simpler) way of doing random compression in VARs would be to use the natural conjugate VAR of (5) instead of our equation by equation approach of (9). However, we have found this to forecast very poorly. Other alternative approaches arise from different ways of drawing φ . We have tried several and found that they yield very similar results and, hence, we will not discuss this issue further. Instead, in this sub-section, we present evidence on the robustness of results to changes in ways the model averaging is done and to changes in the way the variables are ordered.

Our main results use BIC-based weights to do model averaging (i.e. averaging over different randomly drawn compressions). The BICs are calculated using the likelihood of the entire vector of dependent variables, Y_t . Given that we are only forecasting 7 key variables of interest, we can also do model averaging using BICs only for these seven variables. [Table 9](#) (which is of the same format and should be compared to [Table 7](#)) summarizes the forecasting performance for this approach. In a few cases, using BIC for only the 7 variables of interest produces some very small improvements, but this makes very little difference.

To produce our main results, we ordered our dependent variables with our 7 variables of interest coming first. Our equation-by-equation approach to random compression implies different equations have different right-hand side variables (see (9) and subsequent discussion).

So it is possible that the way the variables are ordered will matter, especially when we are compressing the error covariance matrix as in BCVAR_c . [Table 10](#) presents results with the 7 variables of interest being ordered last (labelled $\text{BCVAR}_{c,v.2}$) compared to those of other approaches. BCVAR_c and $\text{BCVAR}_{c,v.2}$ are producing very similar results.

5 Time-variation in Parameters: The Compressed TVP-SV VAR

In macroeconomic forecasting applications, it is often empirically necessary to allow for time-variation in the VAR coefficients and/or the error covariance matrix. There is an increasing literature that shows that ignoring macroeconomic volatility and possible structural changes in coefficients of a VAR can result in bad in-sample fit and poor out-of-sample forecast performance; see for example Clark (2011). Both such extensions add greatly to the computational burden since MCMC methods are usually required. In the context of the constant coefficient VAR with conjugate prior for the VAR coefficients there is a growing literature (e.g. Carriero, Clark and Marcellino, 2015, 2016a and Chan, 2015) investigating various structures for time-varying error covariance matrices which do not lead to excessively large computational demands. However, even these can be restrictive and require the use of MCMC methods which will make them unsuitable for use in extremely large models. Allowing for time-variation in the VAR coefficients (e.g. through assuming coefficients evolve according to a random walk or a Markov switching process) will also greatly increase the burden.

In this section, we show how the compressed VAR methods can be generalized to the case of a VAR with time-varying parameters and stochastic volatilities (BCVAR_{tvp-sv}). Our model becomes

$$Y_{i,t} = \Theta_{i,t}^c (\Phi_i Z_t^i) + \sigma_{i,t} E_{i,t}. \quad (19)$$

Notice that relative to equation (9) now all parameters including the error variances may vary over time and, thus, they have t subscripts, $t = 1, \dots, T$. We also remind the reader that the variables Z_t^i contain lags of the dependent variables and the terms which relate to the error covariances as defined in (8). This TVP-SV VAR model is different from the previous literature because it allows for equation by equation estimation. Papers such as Primiceri

(2005) would specify the VAR in the familiar seemingly unrelated regression form, where all n VAR equations are modeled jointly. Estimation using the latter form can become cumbersome as n increases, since the posterior for both the time-varying regression coefficients and volatilities involves many manipulations involving large data matrices. Using (19), estimation of the BCVAR_{tvp-sv} is reduced to the estimation of n univariate time-varying parameter regressions which is computationally more efficient for large n . Additionally, the possibly large matrix Z_t^i is still compressed using Φ_i as with the BCVAR.

In general, forecasting with TVP-SV VARs is computationally demanding as it typically relies on MCMC methods. In our case, even if we use Φ_i to compress the data, a full Bayesian analysis could be computationally demanding with large n since MCMC methods are required and must be run for each of the n equations. Accordingly, we turn to approximate methods to deal with the TVP-SV aspect of our BCVAR. These are generalizations of those developed by Koop and Korobilis (2013) in the context of a time-varying parameter with time varying error covariance matrix. They use variance discounting methods to model the time-variation in the VAR coefficients and error covariance matrix, and provide analytical formulae for updating them. Thus, in (19), once we draw Φ_i randomly, $\Theta_{i,t}^c$ and $\sigma_{i,t}^2$ can be updated using simple recursive formulae based on the Kalman filter, without relying on computationally intensive MCMC methods.

Adapting Koop and Korobilis (2013), the compressed TVP-SV VAR model involves estimating $\Theta_{i,t}^c$ and $\sigma_{i,t}^2$ by assuming that they evolve according to:

$$\Theta_{i,t}^c = \Theta_{i,t-1}^c + \sqrt{\frac{(1 - \lambda_{i,t}) \text{var}(\Theta_{i,t-1}^c | t-1)}{\lambda_{i,t}}} u_{i,t}, \quad (20)$$

$$\sigma_{i,t}^2 = \kappa_{i,t} \sigma_{i,t-1}^2 + (1 - \kappa_{i,t}) \hat{E}_{i,t}^2. \quad (21)$$

That is, $\Theta_{i,t}^c$ follows a random walk using a forgetting factor approximation to its error covariance matrix. Kalman filtering methods can be used for this equation. For $\sigma_{i,t}^2$ we have an Exponentially Weighted Moving Average filter. $\hat{E}_{i,t}^2$ is the time t prediction error estimated from the i -th equation of the VAR, $u_{i,t} \sim N(0, 1)$, and $\text{var}(\Theta_{i,t-1}^c | t-1)$ is the variance of $\Theta_{i,t-1}^c$ given information up to time $t - 1$ and is produced by the Kalman filter (see Koop and Korobilis, 2013, for details). The crucial parameters in this specification are

the forgetting and decay factors $\lambda_{i,t}$ and $\kappa_{i,t}$. These factors, which are typically in the range of $(0.9, 1)$, control how quickly discounting of past data occurs. For example, if $\lambda_{i,t} = 0.90$ then $\Theta_{i,t}^c$ depends very heavily on recent observations, and changes very rapidly over time. On the other hand, if $\lambda_{i,t} = 0.99$ the discounting of the past is more gradual and $\Theta_{i,t}^c$ varies more smoothly. Finally, when $\lambda_{i,t} = 1$ we go back to the constant parameter VAR. Similar arguments can be made for $\sigma_{i,t}^2$ and its decay factor $\kappa_{i,t}$.

For out-of-sample forecasting, we extend the methods of Koop and Korobilis (2013) by allowing for the decay and forgetting factors to vary over time using simple updating formulae:

$$\lambda_{i,t} = \underline{\lambda} + (1 - \underline{\lambda}) \times \exp \left(-0.5 \times \frac{\widehat{E}_{i,t-1}^2}{\widehat{\sigma}_{i,t-1}^2} \right), \quad (22)$$

$$\kappa_{i,t} = \underline{\kappa} + (1 - \underline{\kappa}) \times \exp \left(-0.5 \times kurt \left(\widehat{E}_{i,t-12:t-1} \right) \right), \quad (23)$$

where $\widehat{\sigma}_{i,t-1}^2$ is the time $t-1$ estimate of the variance and $kurt \left(\widehat{E}_{i,t-12:t-1} \right)$ is the kurtosis of the VAR prediction error, evaluated over the past year (i.e. with monthly data this is based on a rolling sample of 12 observations). $\underline{\lambda}$ and $\underline{\kappa}$ put bounds on the minimum values of the forgetting and decay factors. We set $\underline{\lambda} = 0.98$ and $\underline{\kappa} = 0.94$ which, in the context of monthly data, allow for the possibility of a fairly large amount of time variation.¹⁹

Note that, if the prediction error is close to zero then $\lambda_{it} = 1$ which is the value consistent with the parameters in equation i being constant. In words, if the model forecast well last month, we do not change its parameters this month. However, the larger the prediction error is, the smaller λ_{it} becomes and, thus, a higher degree of parameter change is allowed for. For the decay factor $\kappa_{i,t}$, we use a similar reasoning, except in terms of the kurtosis of the prediction error. As is well known (e.g. from the GARCH literature), assuming that errors are Normally distributed, in times of constant volatility kurtosis will be equal to zero, but in times of increased volatility kurtosis is higher. Allowing for κ_{it} to depend on the kurtosis over the past year is a simple way of allowing $\sigma_{i,t}$ to change more rapidly in unstable times than in stable times. Using these methods, it is straightforward to allow for time-variation in our compressed VAR approach in a computationally simple manner.

¹⁹The idea of allowing the value of the forgetting factor to depend on the most recent prediction error is used, e.g., in Park, Jun, and Kim (1991).

Figure 9, which plots the time series of the predictive density volatilities for the Medium BCVAR_{tvp-sv} against the time series of volatilities obtained from the alternative methods described in section 4, confirms that heteroskedasticity plays a very important role in our data. While the alternative methods allow for some time variation in the volatilities (they are estimated on an expanding window of data), BCVAR_{tvp-sv} is finding a lot more variation. This is particularly true at the time of the financial crisis.

Table 11, Figure 10, and Figure 11 present results on the forecast performance of our BCVAR_{tvp-sv} approach. The story that jumps out is a strong one: adding time variation in the parameters and volatilities leads to substantial improvements in forecast performance. Conventional wisdom has it that allowing for time-variation (particularly in the error covariance matrix) is particularly important for predictive density estimation. In a time of fluctuating volatility, working with a homoskedastic model may not seriously affect point forecasts, but may lead to poor estimates of higher predictive moments. This wisdom is strongly reinforced by our results. The right panels of Table 11 show that in terms of predictive likelihoods, the BCVAR_{tvp-sv} performs much better than our other compressed VAR approaches, and better (with some exceptions) than standard large VAR and factor methods. This is particularly true when focusing on the multivariate predictive performance and short to medium forecast horizons. In addition, improvements relative to the univariate benchmark (as indicated by the stars in the table) are almost always strongly statistically significant. In terms of MSFEs, allowing for time variation in parameters leads to some improvements, but these improvements are not as large as those we find with predictive likelihoods. Again, the multivariate results are particularly strong, for all VAR sizes and forecast horizons. In summary, the message conveyed by Table 11 is a particularly strong one: BCVAR_{tvp-sv} is forecasting better than any other approach considered in this paper.

Figure 10 indicates that, with some exceptions, the reported success in terms of overall point forecast accuracy of the BCVAR_{tvp-sv} relative to the alternative methods we considered (namely, DFM, FAVAR, and BVAR) is not the result of any specific and short-lived episodes but is instead built gradually throughout the forecast evaluation period, as indicated by the increasing lines depicted in the figure. Interestingly, both at $h = 1$ and $h = 12$, the improvements in forecast performance relative to the various alternatives are particularly

notable around the time of the financial crisis, but are not confined to it. [Figure 11](#) provides a similar analysis in terms of the overall density forecast accuracy of the BCVAR_{tvp-sv} model. The left panels of the figure show that at $h = 1$ the previously reported forecast success of the BCVAR_{tvp-sv} is once again built steadily throughout the forecast evaluation period. On the other hand, the right panels of the figure, which focus on $h = 12$, show that while up until the beginning of the last financial crisis the BCVAR_{tvp-sv} is forecasting more accurately than all the alternatives, the 2007-2009 period has a strong negative impact on its density forecast performance.

The preceding results use individual AR(1) forecasting models as the benchmark for comparison. [Table 12](#) uses the Minnesota prior BVAR as the benchmark. It can be seen that many of the forecast improvements of BCVAR_{tvp-sv} over the BVAR are statistically significant.

5.1 Robustness Checks

With our constant coefficient models, we presented robustness checks with respect to: i) which variables were used to calculate the BICs used to construct weights attached to each compression and with ii) whether the ordering of the variables mattered. [Table 13](#) and [Table 14](#) repeat these robustness checks for TVP-SV versions of our approach. In both cases, forecasting performance is very similar. There is a very slight forecast deterioration when the 7 variables of interest are ordered last. But overall we are still finding a high degree of robustness.

Our compressed TVP-SV VAR allows for time-variation in both VAR coefficients and the error covariance matrix. To investigate which of these is more important, [Table 15](#) presents forecasting results for the model with both sorts of time variation (labelled BCVAR_{tvp-sv} in the table) as well as those with only variation in the error covariance matrix (labelled BCVAR_{sv} in the table). Comparing these two models in the table, it can be seen that allowing for time variation in both does lead to some forecast improvements.

We also wish to compare our approaches to other fully Bayesian VAR approaches which allow for time-variation in parameters. The difficulty of doing so is computational. These approaches require the use of MCMC methods which makes them infeasible in large VARs. For instance, the popular TVP-VAR with multivariate stochastic volatility cannot reasonably

be scaled up to large VARs due to the computational burden. D’Agostino, Gambetti and Giannone (2013) carry out a forecast evaluation exercise using this model with three variables and even this is very computationally demanding. One recent approach that shows promise for larger VARs with stochastic volatility is that of Carriero, Clark and Marcellino (2016b). But even their model cannot handle the really large VARs.²⁰ However, we have carried out a comparison of their approach to ours for the Medium VAR and a Small VAR involving only the 7 variables of interest.²¹ The top two panels of [Table 15](#) compares our BCVAR_{tvp-sv} and BCVAR_{sv} approaches to the model of Carriero, Clark and Marcellino (2016b) (labelled BVAR_{ccm}). Results from the three approaches are roughly similar. For the Small VAR, their model tends to forecast slightly better at short horizons than our BCVAR_{sv} . But in the Medium VAR our compressed approaches tend to forecast better (particularly when forecast performance is evaluated using WMSFE). Accordingly, we are finding an ability to forecast as well or better than a sophisticated fully Bayesian VAR with stochastic volatility where such a comparison is possible. But methods such as Carriero, Clark and Marcellino (2016b), which require the use of MCMC methods, are still not at the stage of being suitable for forecasting with hundreds of variables, much less than thousands of variables that would be possible with random compression.

6 Conclusions

In this paper, we have drawn on ideas from the random projection literature to develop methods suitable for use with large VARs. For such methods to be suitable, they must be computationally simple, theoretically justifiable and empirically successful. We argue that the BCVAR methods developed in this paper meet all these goals. In a substantial macroeconomic application, involving VARs with up to 129 variables, we find BCVAR methods to be fast and yield results which are at least as good as or better than competing approaches. And, in contrast to the Minnesota prior BVAR, BCVAR methods can easily be scaled up to much

²⁰Carriero, Clark and Marcellino (2016b) do impulse response analysis in a VAR with 125 variables, but in their forecast evaluation never work with more than 20 variables. The results in [Table 15](#) for the Medium VAR took 25 hours to run on a PC using a modern Core i7 and 32Gb of RAM.

²¹For the autoregressive coefficients we use the asymmetric Minnesota prior with shrinkage hyperparameter $\lambda = 0.01$, and prior mean for own lags $\delta = 0.95$. For all other parameters our priors are fairly noninformative and are exactly the same as in Carriero, Clark and Marcellino (2016b).

higher dimensional models and extended to allow for time-variation in its parameters.

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Tables and Figures

Table 1. Out-of-sample point forecast performance, Medium VAR

| <i>Variable</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> |
|-----------------|--------------|--------------|-----------------|-----------------|--------------------------|--------------|--------------|-----------------|---------------|--------------------------|
| <i>h</i> = 1 | | | | | <i>h</i> = 2 | | | | | |
| PAYEMS | 1.082 | 1.138 | 0.865 | 0.830*** | 0.838*** | 0.921 | 1.000 | 0.554*** | 0.728*** | 0.732*** |
| CPIAUCSL | 1.142 | 1.017 | 0.949 | 0.958 | 0.967 | 1.086 | 1.037 | 0.999 | 0.940 | 0.936* |
| FEDFUNDS | 2.278 | 1.848 | 2.760 | 1.023 | 0.962 | 1.441 | 1.424 | 2.448 | 0.974 | 0.945 |
| INDPRO | 0.863*** | 0.879** | 0.810** | 0.828*** | 0.889*** | 0.909 | 0.952 | 0.825* | 0.931 | 0.929* |
| UNRATE | 0.878 | 0.840** | 0.783*** | 0.803*** | 0.848*** | 0.894 | 0.908 | 0.805** | 0.844*** | 0.869** |
| PPIFGS | 1.000 | 1.002 | 0.980 | 0.970 | 0.993 | 1.052 | 1.037 | 1.083 | 1.029 | 1.012 |
| GS10 | 1.141 | 0.988 | 1.092 | 0.996 | 1.013 | 1.038 | 1.023 | 1.082 | 1.003 | 1.003 |
| <i>h</i> = 3 | | | | | <i>h</i> = 6 | | | | | |
| PAYEMS | 0.846 | 0.915 | 0.522*** | 0.683*** | 0.687*** | 0.951 | 0.903 | 0.686* | 0.747** | 0.738** |
| CPIAUCSL | 1.096 | 1.031 | 1.042 | 0.982 | 0.978 | 1.042 | 0.979 | 1.057 | 1.003 | 0.995 |
| FEDFUNDS | 1.289 | 1.272 | 1.858 | 1.017 | 1.001 | 1.198 | 1.017 | 1.195 | 0.991 | 0.986 |
| INDPRO | 0.928 | 0.991 | 0.931 | 0.939 | 0.949 | 0.959 | 1.024 | 1.024 | 0.970 | 0.957 |
| UNRATE | 0.942 | 0.959 | 0.850* | 0.871** | 0.866*** | 0.993 | 0.995 | 0.947 | 0.939* | 0.946* |
| PPIFGS | 1.032 | 1.016 | 1.102 | 1.050 | 1.042 | 1.047 | 1.026 | 1.135 | 1.059 | 1.043 |
| GS10 | 1.038 | 1.036 | 1.140 | 1.046 | 1.032 | 1.006 | 1.015 | 1.115 | 1.036 | 1.038 |
| <i>h</i> = 9 | | | | | <i>h</i> = 12 | | | | | |
| PAYEMS | 1.005 | 0.936 | 0.824 | 0.838 | 0.843 | 1.015 | 0.963 | 0.931 | 0.934 | 0.935 |
| CPIAUCSL | 1.001 | 0.960 | 1.036 | 0.979 | 0.961 | 1.007 | 0.969 | 1.069 | 1.016 | 1.012 |
| FEDFUNDS | 1.133 | 0.945 | 0.991 | 0.921 | 0.950 | 1.137 | 0.975 | 1.077 | 0.991 | 0.996 |
| INDPRO | 0.958 | 1.009 | 1.024 | 0.967 | 0.978 | 0.981 | 1.011 | 1.004 | 0.974 | 0.975 |
| UNRATE | 1.009 | 1.001 | 0.972 | 0.954 | 0.951 | 1.007 | 1.010 | 1.008 | 0.968 | 0.968 |
| PPIFGS | 1.017 | 1.004 | 1.116 | 1.055 | 1.042 | 1.018 | 1.000 | 1.140 | 1.070 | 1.053 |
| GS10 | 0.997 | 0.997 | 1.025 | 1.005 | 1.016 | 1.012 | 1.000 | 1.052 | 1.029 | 1.023 |

This table reports the ratio between the MSFE of model i and the MSFE of the benchmark AR(1) for the Medium size VAR, computed as

$$MSFE_{ijh} = \frac{\sum_{\tau=\underline{t}}^{\bar{t}-h} e_{i,j,\tau+h}^2}{\sum_{\tau=\underline{t}}^{\bar{t}-h} e_{bcmk,j,\tau+h}^2},$$

where $e_{i,j,\tau+h}^2$ and $e_{bcmk,j,\tau+h}^2$ are the squared forecast errors of variable j at time τ and forecast horizon h generated by model i and the AR(1) model, respectively. \underline{t} and \bar{t} denote the start and end of the out-of-sample period, $i \in \{DFM, FAVAR, BVAR, BCVAR, BCVAR_c\}$, $j \in \{PAYEMS, CPIAUCSL, FEDFUNDS, INDPRO, UNRATE, PPIFGS, GS10\}$, and $h \in \{1, 2, 3, 6, 9, 12\}$. All forecasts are generated out-of-sample using recursive estimates of the models, with the out of sample period starting in 1987:07 and ending in 2014:12. Bold numbers indicate the lowest MSFE across all models for a given variable-forecast horizon pair. * significance at the 10% level; ** significance at the 5% level; *** significance at the 1% level.

Table 2. Out-of-sample point forecast performance, Large VAR

| <i>Variable</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> |
|-----------------|----------------|--------------|-----------------|----------------|--------------------------|----------------|---------------|-----------------|--------------|--------------------------|
| <i>h</i> = 1 | | | | | | <i>h</i> = 2 | | | | |
| PAYEMS | 1.137 | 1.146 | 0.792** | 0.831*** | 0.864*** | 0.869 | 0.914 | 0.512*** | 0.747*** | 0.762*** |
| CPIAUCSL | 1.148 | 1.017 | 1.000 | 0.951 | 0.942* | 1.165 | 1.085 | 1.099 | 0.911** | 0.898*** |
| FEDFUNDS | 2.449 | 1.731 | 2.449 | 0.949 | 0.944 | 1.961 | 1.376 | 2.532 | 0.963 | 0.924 |
| INDPRO | 0.824** | 0.877*** | 0.778*** | 0.820*** | 0.904*** | 0.855 | 0.918* | 0.771** | 0.907** | 0.935* |
| UNRATE | 0.851** | 0.798*** | 0.770*** | 0.809*** | 0.897*** | 0.803** | 0.841*** | 0.794** | 0.857*** | 0.893*** |
| PPIFGS | 1.042 | 1.002 | 1.041 | 0.967 | 0.991 | 1.157 | 1.057 | 1.166 | 1.013 | 1.006 |
| GS10 | 1.015 | 1.001 | 1.113 | 0.997 | 1.002 | 0.999 | 1.023 | 1.116 | 0.996 | 1.009 |
| <i>h</i> = 3 | | | | | | <i>h</i> = 6 | | | | |
| PAYEMS | 0.780 | 0.842* | 0.467*** | 0.717*** | 0.732*** | 0.841 | 0.920* | 0.604** | 0.764** | 0.783*** |
| CPIAUCSL | 1.132 | 1.061 | 1.146 | 0.923** | 0.926** | 1.045 | 1.018 | 0.988 | 0.897*** | 0.885*** |
| FEDFUNDS | 1.714 | 1.063 | 2.174 | 1.001 | 0.989 | 1.247 | 0.974 | 1.234 | 0.998 | 0.963 |
| INDPRO | 0.900 | 0.944 | 0.852 | 0.927** | 0.938* | 0.939 | 0.981 | 0.980 | 0.975 | 0.971 |
| UNRATE | 0.855* | 0.911** | 0.840* | 0.906** | 0.930** | 0.906** | 0.956*** | 0.887** | 0.927** | 0.962 |
| PPIFGS | 1.143 | 1.003 | 1.168 | 1.004 | 1.007 | 1.104 | 1.008 | 1.088 | 1.001 | 0.993 |
| GS10 | 1.040 | 1.024 | 1.211 | 1.050 | 1.047 | 1.038 | 1.009 | 1.098 | 1.031 | 1.022 |
| <i>h</i> = 9 | | | | | | <i>h</i> = 12 | | | | |
| PAYEMS | 0.877 | 0.962** | 0.762 | 0.858* | 0.863** | 0.926 | 0.994 | 0.922 | 0.962 | 0.956 |
| CPIAUCSL | 1.047 | 0.998 | 0.910 | 0.848*** | 0.841*** | 1.065 | 1.002 | 0.898 | 0.880*** | 0.860*** |
| FEDFUNDS | 1.113 | 1.008 | 1.179 | 0.970 | 1.025 | 1.062 | 0.964* | 1.281 | 1.010 | 0.997 |
| INDPRO | 0.962 | 1.009 | 1.003 | 0.987 | 0.988 | 0.957 | 1.006 | 1.043 | 0.998 | 1.000 |
| UNRATE | 0.949** | 0.987 | 0.965 | 0.979 | 0.987 | 0.954** | 0.992 | 1.002 | 0.998 | 0.985 |
| PPIFGS | 1.059 | 1.002 | 1.049 | 0.973 | 0.973 | 1.096 | 1.002 | 1.042 | 0.989 | 0.981 |
| GS10 | 0.998 | 0.998 | 1.043 | 0.995 | 1.022 | 1.001 | 0.990 | 1.043 | 1.012 | 1.000 |

This table reports the ratio between the MSFE of model i and the MSFE of the benchmark AR(1) for the Large size VAR, across a number of different forecast horizons h . $i \in \{DFM, FAVAR, BVAR, BCVAR, BCVAR_c\}$ and $h \in \{1, 2, 3, 6, 9, 12\}$. See notes under Table 1 for additional details.

Table 3. Out-of-sample point forecast performance, Huge VAR

| <i>Variable</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> |
|-----------------|------------|-----------------|-----------------|--------------|--------------------------|---------------|--------------|-----------------|----------------|--------------------------|
| <i>h</i> = 1 | | | | | | <i>h</i> = 2 | | | | |
| PAYEMS | 0.789** | 1.068 | 0.748*** | 0.777*** | 0.796*** | 0.710* | 0.801 | 0.481*** | 0.640*** | 0.671*** |
| CPIAUCSL | 0.930 | 0.925 | 0.860** | 0.928** | 0.935* | 1.003 | 0.996 | 0.932 | 0.887** | 0.892** |
| FEDFUNDS | 2.120 | 1.669 | 2.061 | 0.965 | 1.013 | 1.766 | 1.338 | 2.178 | 0.962 | 0.892 |
| INDPRO | 0.830** | 0.858** | 0.778*** | 0.844*** | 0.902*** | 0.860 | 0.884 | 0.801* | 0.945 | 0.920** |
| UNRATE | 0.807** | 0.740*** | 0.796** | 0.810*** | 0.860*** | 0.811** | 0.829** | 0.769** | 0.852*** | 0.852*** |
| PPIFGS | 0.940 | 0.984 | 0.938 | 0.974 | 1.012 | 1.065 | 1.047 | 1.063 | 1.013 | 1.019 |
| GS10 | 1.111 | 1.037 | 1.103 | 1.009 | 1.015 | 1.036 | 1.057 | 1.136 | 1.005 | 1.044 |
| <i>h</i> = 3 | | | | | | <i>h</i> = 6 | | | | |
| PAYEMS | 0.715 | 0.726 | 0.474*** | 0.611*** | 0.622*** | 0.923 | 0.828 | 0.620 | 0.668** | 0.706** |
| CPIAUCSL | 0.979 | 0.988 | 0.979 | 0.912 | 0.904* | 0.961 | 0.922 | 1.044 | 0.931 | 0.916 |
| FEDFUNDS | 1.526 | 1.104 | 1.819 | 0.967 | 0.987 | 1.395 | 0.959 | 1.325 | 0.991 | 0.988 |
| INDPRO | 0.943 | 0.950 | 0.893 | 0.950 | 0.938 | 1.035 | 0.977 | 1.022 | 0.967 | 0.983 |
| UNRATE | 0.888 | 0.868* | 0.836* | 0.876** | 0.882*** | 0.981 | 0.931* | 0.886* | 0.924** | 0.943* |
| PPIFGS | 1.086 | 1.040 | 1.089 | 1.034 | 1.048 | 1.112 | 1.057 | 1.151 | 1.063 | 1.041 |
| GS10 | 1.067 | 1.094 | 1.215 | 1.049 | 1.064 | 1.073 | 1.038 | 1.179 | 1.022 | 1.042 |
| <i>h</i> = 9 | | | | | | <i>h</i> = 12 | | | | |
| PAYEMS | 1.001 | 0.916 | 0.743 | 0.766 | 0.760* | 1.065 | 0.996 | 0.870 | 0.848 | 0.866 |
| CPIAUCSL | 0.944 | 0.887** | 1.022 | 0.895 | 0.885 | 0.947 | 0.915*** | 1.036 | 0.901 | 0.872** |
| FEDFUNDS | 1.279 | 0.995 | 1.115 | 0.969 | 0.995 | 1.225 | 0.976 | 1.151 | 1.023 | 1.035 |
| INDPRO | 1.043 | 1.004 | 1.068 | 0.975 | 0.990 | 0.993 | 0.997 | 1.074 | 0.989 | 1.012 |
| UNRATE | 1.019 | 0.967* | 0.938 | 0.951 | 0.957 | 1.014 | 0.981 | 0.982 | 0.979 | 0.989 |
| PPIFGS | 1.060 | 1.011 | 1.149 | 1.047 | 1.035 | 1.100 | 1.032 | 1.182 | 1.073 | 1.042 |
| GS10 | 1.023 | 1.000 | 1.074 | 1.006 | 1.024 | 1.034 | 1.003 | 1.081 | 1.013 | 1.006 |

This table reports the ratio between the MSFE of model i and the MSFE of the benchmark AR(1) for the Huge size VAR, across a number of different forecast horizons h . $i \in \{DFM, FAVAR, BVAR, BCVAR, BCVAR_c\}$ and $h \in \{1, 2, 3, 6, 9, 12\}$. See notes under Table 1 for additional details.

Table 4. Out-of-sample density forecast performance, Medium VAR

| Variable | DFM | FAVAR | BVAR | BCVAR | BCVAR _c | DFM | FAVAR | BVAR | BCVAR | BCVAR _c |
|--------------|--------------|--------------|-----------------|-----------------|--------------------|---------------|---------------|-----------------|---------------|--------------------|
| <i>h</i> = 1 | | | | | | <i>h</i> = 2 | | | | |
| PAYEMS | 0.066*** | 0.030 | 0.218*** | 0.086*** | 0.083*** | 0.117*** | 0.061* | 0.366*** | 0.158*** | 0.163*** |
| CPIAUCSL | -0.115 | -0.055 | -0.674 | 0.003 | 0.156 | -0.266 | -0.280 | -1.669 | -0.263 | -0.247 |
| FEDFUNDS | -0.012 | 0.043*** | 0.131*** | 0.006 | 0.005 | 0.028 | 0.042*** | 0.115** | 0.022*** | 0.022*** |
| INDPRO | -0.105 | 0.046 | -0.098 | -0.063 | 0.028 | 0.008 | 0.028 | -0.049 | 0.084** | 0.109** |
| UNRATE | 0.083** | 0.121*** | 0.167*** | 0.105*** | 0.081*** | 0.072** | 0.060** | 0.131*** | 0.077*** | 0.062*** |
| PPIFGS | 0.025 | -0.033 | -0.448 | -0.071 | 0.020 | -0.043 | -0.135 | -0.725 | 0.019 | -0.063 |
| GS10 | -0.029 | 0.007 | 0.015 | -0.001 | -0.007 | -0.011 | -0.017 | -0.009 | -0.008 | -0.016 |
| <i>h</i> = 3 | | | | | | <i>h</i> = 6 | | | | |
| PAYEMS | 0.124*** | 0.085** | 0.364*** | 0.172*** | 0.185*** | 0.050 | 0.071 | 0.245*** | 0.144*** | 0.168*** |
| CPIAUCSL | 0.034 | 0.043 | -0.984 | -0.095 | -0.017 | -0.007 | 0.004 | -0.860 | -0.220 | -0.249 |
| FEDFUNDS | 0.021 | 0.023* | 0.115*** | 0.014 | 0.014* | 0.013 | 0.015** | 0.119*** | 0.017** | 0.011 |
| INDPRO | 0.144 | 0.090 | -0.001 | 0.125 | 0.073*** | -0.005 | 0.052 | -0.227 | -0.014 | 0.038*** |
| UNRATE | 0.041 | 0.024 | 0.109*** | 0.065*** | 0.062*** | 0.022 | 0.007 | 0.058*** | 0.042*** | 0.040*** |
| PPIFGS | -0.081 | 0.044 | -0.483 | 0.049 | -0.098 | -0.063 | 0.003 | -0.807 | -0.172 | -0.100 |
| GS10 | 0.012 | 0.014 | 0.010 | 0.013 | 0.003 | 0.003 | 0.001 | 0.002 | -0.003 | -0.013 |
| <i>h</i> = 9 | | | | | | <i>h</i> = 12 | | | | |
| PAYEMS | 0.005 | 0.038 | 0.092 | 0.096*** | 0.084*** | 0.023 | 0.038 | 0.040 | 0.074*** | 0.089*** |
| CPIAUCSL | -0.022 | 0.220 | -0.746 | -0.083 | -0.184 | -0.091 | -0.037 | -0.905 | -0.254 | -0.312 |
| FEDFUNDS | 0.007 | 0.008 | 0.119*** | 0.008 | 0.005 | -0.014 | -0.002 | 0.109*** | -0.006 | -0.008 |
| INDPRO | -0.038 | -0.067 | -0.152 | -0.012 | -0.077 | 0.098 | -0.007 | -0.018 | 0.128 | 0.149 |
| UNRATE | 0.015 | 0.010 | 0.040 | 0.048*** | 0.036*** | -0.002 | 0.000 | 0.033 | 0.024** | 0.020** |
| PPIFGS | -0.006 | 0.106 | -0.413 | -0.070 | 0.060 | -0.001 | 0.120 | -0.391 | -0.144 | -0.108 |
| GS10 | 0.009 | 0.009** | 0.041** | 0.011 | 0.001 | -0.016 | -0.001 | 0.010 | -0.003 | -0.014 |

This table reports the average log predictive likelihood (ALPL) differential between model i and the benchmark AR(1) for the Medium size VAR, computed as

$$ALPL_{ijh} = \frac{1}{\bar{t} - \underline{t} - h + 1} \sum_{\tau=\underline{t}}^{\bar{t}-h} (LPL_{i,j,\tau+h} - LPL_{bcmk,j,\tau+h}),$$

where $LPL_{i,j,\tau+h}$ and $LPL_{bcmk,j,\tau+h}$ are the log predictive likelihoods of variable j at time τ and forecast horizon h generated by model i and the AR(1) model, respectively. \underline{t} and \bar{t} denote the start and end of the out-of-sample period, $i \in \{DFM, FAVAR, BVAR, BCVAR, BCVAR_c\}$, $j \in \{PAYEMS, CPIAUCSL, FEDFUNDS, INDPRO, UNRATE, PPIFGS, GS10\}$, and $h \in \{1, 2, 3, 6, 9, 12\}$. All density forecasts are generated out-of-sample using recursive estimates of the models, with the out of sample period starting in 1987:07 and ending in 2014:12. Bold numbers indicate the highest ALPL across all models for a given variable-forecast horizon pair. * significance at the 10% level; ** significance at the 5% level; *** significance at the 1% level.

Table 5. Out-of-sample density forecast performance, Large VAR

| <i>Variable</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> |
|-----------------|---------------|---------------|-----------------|----------------|--------------------------|----------------|--------------|-----------------|----------------|--------------------------|
| | <i>h</i> = 1 | | | | | <i>h</i> = 2 | | | | |
| PAYEMS | 0.065*** | -0.008 | 0.254*** | 0.076*** | 0.063*** | 0.138*** | 0.079*** | 0.406*** | 0.140*** | 0.137*** |
| CPIAUCSL | -0.223 | -0.002 | -0.787 | 0.104** | -0.026 | -0.800 | 0.061 | -2.100 | 0.032 | 0.182** |
| FEDFUNDS | 0.022 | 0.042** | 0.147** | 0.004 | -0.002 | -0.002 | 0.018 | -0.026 | 0.000 | 0.009 |
| INDPRO | 0.020 | -0.030 | -0.039 | 0.011 | -0.047 | 0.162*** | 0.064 | 0.181** | 0.065*** | 0.090** |
| UNRATE | 0.114*** | 0.127*** | 0.170*** | 0.089*** | 0.051*** | 0.118*** | 0.080*** | 0.150*** | 0.083*** | 0.058*** |
| PPIFGS | -0.191 | -0.021 | -0.679 | 0.096* | -0.024 | -0.477 | -0.091 | -1.105 | 0.053 | -0.048 |
| GS10 | 0.036* | 0.020 | -0.027 | 0.006 | 0.000 | 0.017 | 0.014 | 0.017 | 0.021 | -0.003 |
| | <i>h</i> = 3 | | | | | <i>h</i> = 6 | | | | |
| PAYEMS | 0.141*** | 0.060*** | 0.416*** | 0.159*** | 0.160*** | 0.082** | 0.029 | 0.300*** | 0.121*** | 0.140*** |
| CPIAUCSL | -0.246 | -0.086 | -1.873 | -0.073 | -0.075 | -0.091 | 0.078 | -0.826 | 0.087** | -0.061 |
| FEDFUNDS | -0.046 | 0.011 | 0.029 | 0.004 | 0.006 | -0.007 | -0.002 | 0.159*** | 0.003 | 0.012* |
| INDPRO | -0.022 | 0.005 | -0.056 | 0.010 | -0.021 | 0.069** | -0.128 | -0.315 | -0.063 | -0.149 |
| UNRATE | 0.081*** | 0.035** | 0.119*** | 0.061*** | 0.054*** | 0.039*** | 0.017** | 0.092*** | 0.042*** | 0.023** |
| PPIFGS | -0.193 | -0.061 | -1.087 | 0.029 | -0.125 | -0.064 | 0.049 | -0.791 | 0.007 | -0.099 |
| GS10 | -0.001 | -0.010 | -0.028 | 0.000 | -0.008 | -0.005 | -0.005 | 0.004 | -0.004 | -0.009 |
| | <i>h</i> = 9 | | | | | <i>h</i> = 12 | | | | |
| PAYEMS | 0.059** | 0.019 | 0.165*** | 0.095*** | 0.097*** | 0.044 | 0.003 | 0.063 | 0.034* | 0.032 |
| CPIAUCSL | -0.157 | -0.040 | -0.872 | -0.104 | -0.158 | 0.032 | -0.016 | -0.721 | 0.059 | -0.058 |
| FEDFUNDS | -0.006 | -0.006 | 0.145*** | -0.002 | -0.003 | -0.001 | -0.002 | 0.133*** | -0.003 | -0.004 |
| INDPRO | 0.085 | 0.029 | -0.178 | 0.027*** | 0.050 | 0.083 | 0.102 | -0.188 | 0.078 | 0.180 |
| UNRATE | 0.033*** | -0.002 | 0.050** | 0.017** | 0.013* | 0.018** | -0.002 | 0.017 | 0.002 | 0.008 |
| PPIFGS | -0.036 | -0.021 | -0.647 | -0.047 | -0.047 | 0.014 | 0.061 | -0.549 | -0.021 | -0.138 |
| GS10 | 0.004 | -0.001 | 0.034 | 0.001 | -0.017 | 0.000 | 0.012 | 0.029 | -0.009 | -0.022 |

This table reports the average log predictive likelihood (ALPL) differential between model i and the benchmark AR(1) for the Large size VAR, across a number of different forecast horizons h . $i \in \{DFM, FAVAR, BVAR, BCVAR, BCVAR_c\}$ and $h \in \{1, 2, 3, 6, 9, 12\}$. See notes under Table 4 for additional details.

Table 6. Out-of-sample density forecast performance, Huge VAR

| <i>Variable</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> |
|-----------------|--------------|-----------------|-----------------|-----------------|--------------------------|---------------|---------------|-----------------|-----------------|--------------------------|
| <i>h</i> = 1 | | | | | | <i>h</i> = 2 | | | | |
| PAYEMS | -0.189*** | 0.061*** | 0.302*** | 0.104*** | 0.102*** | 0.224*** | 0.155*** | 0.471*** | 0.196*** | 0.196*** |
| CPIAUCSL | -0.005 | 0.041 | -0.362 | 0.025 | 0.052 | -0.419 | -0.210 | -2.118 | 0.098*** | 0.095** |
| FEDFUNDS | 0.030 | 0.052*** | 0.291*** | 0.014** | 0.010** | 0.019 | 0.036* | 0.247*** | 0.013* | 0.014** |
| INDPRO | -0.051 | -0.029 | -0.311 | 0.092*** | 0.026 | 0.238* | 0.170** | -0.057 | 0.041 | 0.179 |
| UNRATE | 0.130*** | 0.157*** | 0.125** | 0.095*** | 0.079*** | 0.102*** | 0.092*** | 0.163*** | 0.076*** | 0.079*** |
| PPIFGS | -0.111 | 0.002 | -1.029 | 0.059* | -0.087 | -0.241 | -0.157 | -1.813 | -0.064 | -0.015 |
| GS10 | -0.008 | -0.007 | 0.006 | -0.001 | 0.000 | 0.006 | -0.010 | -0.009 | 0.012 | -0.001 |
| <i>h</i> = 3 | | | | | | <i>h</i> = 6 | | | | |
| PAYEMS | -0.197*** | 0.168*** | 0.447*** | 0.229*** | 0.225*** | 0.090* | 0.097** | 0.296*** | 0.199*** | 0.191*** |
| CPIAUCSL | -0.190 | -0.070 | -2.294 | 0.000 | 0.121*** | -0.119 | 0.087 | -2.185 | 0.227 | 0.042 |
| FEDFUNDS | 0.016 | 0.032* | 0.228*** | 0.022** | 0.016** | 0.003 | 0.013* | 0.186*** | 0.007 | 0.013 |
| INDPRO | -0.025 | 0.029 | 0.065 | 0.052*** | 0.043*** | 0.082 | -0.028 | -0.151 | 0.056* | -0.088 |
| UNRATE | 0.059** | 0.061*** | 0.106** | 0.067*** | 0.048*** | 0.017 | 0.028** | 0.084*** | 0.036** | 0.030*** |
| PPIFGS | -0.283 | -0.002 | -1.315 | 0.086 | -0.062 | -0.124 | -0.100 | -1.594 | 0.003 | -0.173 |
| GS10 | 0.018 | 0.012 | -0.027 | 0.032 | 0.009 | -0.014 | 0.000 | -0.024 | 0.012 | -0.005 |
| <i>h</i> = 9 | | | | | | <i>h</i> = 12 | | | | |
| PAYEMS | 0.005 | 0.037 | 0.128 | 0.129*** | 0.123*** | 0.019 | 0.019 | 0.077 | 0.100*** | 0.110*** |
| CPIAUCSL | 0.212 | 0.002 | -0.995 | -0.032 | 0.059 | 0.060 | -0.239 | -1.661 | 0.016 | -0.171 |
| FEDFUNDS | 0.004 | 0.011*** | 0.275*** | 0.014* | 0.010 | 0.002 | 0.007 | 0.211*** | -0.002 | -0.001 |
| INDPRO | 0.110 | 0.011 | -0.183 | 0.081 | 0.050** | 0.062 | -0.038 | -0.174 | 0.021* | -0.057 |
| UNRATE | -0.002 | 0.007 | 0.045 | 0.026* | 0.028** | 0.008 | 0.019** | 0.034 | 0.029** | 0.021** |
| PPIFGS | 0.022 | 0.064 | -1.227 | 0.099 | 0.039 | -0.189 | -0.130 | -0.724 | -0.144 | -0.274 |
| GS10 | -0.003 | 0.017 | 0.039 | 0.008 | -0.011 | -0.002 | 0.007 | 0.034 | -0.005 | -0.021 |

This table reports the average log predictive likelihood (ALPL) differential between model i and the benchmark AR(1) for the Huge size VAR, across a number of different forecast horizons h . $i \in \{DFM, FAVAR, BVAR, BCVAR, BCVAR_c\}$ and $h \in \{1, 2, 3, 6, 9, 12\}$. See notes under Table 4 for additional details.

Table 7. Out-of-sample forecast performance: Multivariate results

| $Fcst\ h.$ | <i>Medium VAR</i> | | | | | | | | | |
|------------|-------------------|--------------|-------------|-----------------|--------------------------|---------------|--------------|-----------------|-----------------|--------------------------|
| | <i>WMSFE</i> | | | | | <i>MVALPL</i> | | | | |
| | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> |
| h= 1 | 1.158 | 1.066 | 1.132 | 0.916*** | 0.935*** | 0.551*** | 0.770*** | 0.979*** | 0.925*** | 0.285*** |
| h= 2 | 1.051 | 1.052 | 1.115 | 0.929** | 0.926*** | 0.832*** | 0.818*** | 1.068*** | 1.021*** | 0.401*** |
| h= 3 | 1.027 | 1.031 | 1.064 | 0.944* | 0.940* | 0.890*** | 0.874*** | 1.097*** | 1.046*** | 0.356*** |
| h= 6 | 1.027 | 0.992 | 1.017 | 0.961 | 0.954 | 0.868*** | 0.837*** | 1.030*** | 1.009*** | 0.296*** |
| h= 9 | 1.017 | 0.977 | 0.995 | 0.957 | 0.960 | 0.850*** | 0.858*** | 1.021*** | 1.017*** | 0.254*** |
| h=12 | 1.025 | 0.988 | 1.039 | 0.996 | 0.994 | 0.877*** | 0.867*** | 0.927*** | 0.886*** | 0.176*** |
| | <i>Large VAR</i> | | | | | | | | | |
| | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> |
| | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> |
| h= 1 | 1.160 | 1.048 | 1.103 | 0.906*** | 0.939*** | 0.710*** | 0.820*** | 0.988*** | 0.933*** | 0.253*** |
| h= 2 | 1.117 | 1.033 | 1.148 | 0.919*** | 0.924*** | 0.847*** | 0.844*** | 0.895*** | 1.011*** | 0.360*** |
| h= 3 | 1.083 | 0.981 | 1.126 | 0.934** | 0.939*** | 0.886*** | 0.835*** | 0.945*** | 1.023*** | 0.264*** |
| h= 6 | 1.016 | 0.980** | 0.977 | 0.937** | 0.935** | 0.937*** | 0.828*** | 1.187*** | 1.054*** | 0.276*** |
| h= 9 | 0.999 | 0.994 | 0.979 | 0.939** | 0.951** | 0.935*** | 0.828*** | 1.198*** | 1.043*** | 0.271*** |
| h=12 | 1.009 | 0.993* | 1.026 | 0.975 | 0.965** | 0.886*** | 0.837*** | 1.017*** | 0.956*** | 0.157* |
| | <i>Huge VAR</i> | | | | | | | | | |
| | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> |
| | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> |
| h= 1 | 1.049 | 1.009 | 1.017 | 0.907*** | 0.940*** | 0.950*** | 0.935*** | 0.905*** | 0.996*** | 0.303*** |
| h= 2 | 1.037 | 0.996 | 1.053 | 0.909*** | 0.908*** | 1.053*** | 0.971*** | 0.944*** | 1.139*** | 0.406*** |
| h= 3 | 1.030 | 0.970 | 1.045 | 0.916** | 0.922** | 1.049*** | 0.999*** | 0.974*** | 1.179*** | 0.368*** |
| h= 6 | 1.063 | 0.955 | 1.026 | 0.933 | 0.940 | 0.957*** | 0.995*** | 0.830*** | 1.131*** | 0.269*** |
| h= 9 | 1.049 | 0.965 | 1.009 | 0.938 | 0.943 | 0.972*** | 0.954*** | 0.879*** | 1.076*** | 0.243*** |
| h=12 | 1.052 | 0.984 | 1.049 | 0.969 | 0.968 | 0.934*** | 0.910*** | 0.709** | 1.009*** | 0.145 |

The left half of this table reports the ratio between the multivariate weighted mean squared forecast error (WMSFE) of model i and the WMSFE of the benchmark AR(1) model, computed as

$$WMSFE_{ih} = \frac{\sum_{\tau=\underline{t}}^{\bar{t}-h} we_{i,\tau+h}}{\sum_{\tau=\underline{t}}^{\bar{t}-h} we_{bcmk,\tau+h}},$$

where $we_{i,\tau+h} = (e'_{i,\tau+h} \times W \times e_{i,\tau+h})$ and $we_{bcmk,\tau+h} = (e'_{bcmk,\tau+h} \times W \times e_{bcmk,\tau+h})$ denote the weighted forecast errors of model i and the benchmark model at time $\tau+h$, $e_{i,\tau+h}$ and $e_{bcmk,\tau+h}$ are the $(N \times 1)$ vector of forecast errors, and W is an $(N \times N)$ matrix of weights. We set $N = 7$, to focus on the following key seven series, $\{PAYEMS, CPIAUCSL, FEDFUNDS, INDPRO, UNRATE, PPIFGS, GS10\}$. In addition, we set the matrix W to be a diagonal matrix featuring on the diagonal the inverse of the variances of the series to be forecast. \underline{t} and \bar{t} denote the start and end of the out-of-sample period, $i \in \{DFM, FAVAR, BVAR, BCVAR, BCVAR_c\}$, and $h \in \{1, 2, 3, 6, 9, 12\}$. The right half of the table shows the multivariate average log predictive likelihood differentials between model i and the benchmark AR(1), computed as

$$MVALPL_{ih} = \frac{1}{\bar{t} - \underline{t} - h + 1} \sum_{\tau=\underline{t}}^{\bar{t}-h} (MVLPL_{i,\tau+h} - MVLPL_{bcmk,\tau+h}),$$

where $MVLPL_{i,\tau+h}$ and $MVLPL_{bcmk,\tau+h}$ denote the multivariate log predictive likelihoods of model i and the benchmark model at time $\tau+h$, and are computed under the assumption of joint normality. All forecasts are generated out-of-sample using recursive estimates of the models, with the out of sample period starting in 1987:07 and ending in 2014:12. Bold numbers indicate the lowest WMSFE and highest MVALPL across all models for any given VAR size - forecast horizon pair. * significance at the 10% level; ** significance at the 5% level; *** significance at the 1% level.

Table 8. Out-of-sample forecast performance: Multivariate results, BVAR as the benchmark

| <i>Fcst h.</i> | <i>Medium VAR</i> | | | | | | | | | |
|----------------|-------------------|--------------|-------------|-----------------|--------------------------|---------------|--------------|-------------|---------------|--------------------------|
| | <i>WMSFE</i> | | | | | <i>MVALPL</i> | | | | |
| | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> |
| h= 1 | 1.023 | 0.942* | 1.000 | 0.810*** | 0.826*** | -0.428 | -0.209 | 0.000 | -0.054 | -0.694 |
| h= 2 | 0.943 | 0.943 | 1.000 | 0.833*** | 0.830*** | -0.235 | -0.249 | 0.000 | -0.047 | -0.666 |
| h= 3 | 0.965 | 0.969 | 1.000 | 0.887* | 0.883* | -0.207 | -0.223 | 0.000 | -0.051 | -0.740 |
| h= 6 | 1.010 | 0.975 | 1.000 | 0.944 | 0.938 | -0.162 | -0.193 | 0.000 | -0.021 | -0.734 |
| h= 9 | 1.022 | 0.982 | 1.000 | 0.962 | 0.964 | -0.171 | -0.163 | 0.000 | -0.004 | -0.767 |
| h=12 | 0.986 | 0.951 | 1.000 | 0.959 | 0.957 | -0.050 | -0.060 | 0.000 | -0.041 | -0.751 |
| | <i>Large VAR</i> | | | | | | | | | |
| | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> |
| h= 1 | 1.052 | 0.951 | 1.000 | 0.821*** | 0.852*** | -0.278 | -0.168 | 0.000 | -0.055 | -0.735 |
| h= 2 | 0.973 | 0.900** | 1.000 | 0.801*** | 0.805** | -0.048 | -0.051 | 0.000 | 0.116 | -0.536 |
| h= 3 | 0.962 | 0.872** | 1.000 | 0.829** | 0.834* | -0.059 | -0.110 | 0.000 | 0.078 | -0.682 |
| h= 6 | 1.040 | 1.004 | 1.000 | 0.960 | 0.958 | -0.250 | -0.359 | 0.000 | -0.133 | -0.911 |
| h= 9 | 1.020 | 1.015 | 1.000 | 0.959 | 0.971 | -0.263 | -0.370 | 0.000 | -0.154 | -0.926 |
| h=12 | 0.983 | 0.968 | 1.000 | 0.950 | 0.940 | -0.131 | -0.180 | 0.000 | -0.061 | -0.861 |
| | <i>Huge VAR</i> | | | | | | | | | |
| | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> |
| h= 1 | 1.032 | 0.993 | 1.000 | 0.892*** | 0.925** | 0.045 | 0.030 | 0.000 | 0.091 | -0.602 |
| h= 2 | 0.985 | 0.946 | 1.000 | 0.863*** | 0.862*** | 0.109 | 0.027 | 0.000 | 0.195 | -0.538 |
| h= 3 | 0.985 | 0.927 | 1.000 | 0.876** | 0.882* | 0.074 | 0.025 | 0.000 | 0.205 | -0.606 |
| h= 6 | 1.037 | 0.932 | 1.000 | 0.910* | 0.917 | 0.126 | 0.165 | 0.000 | 0.301 | -0.561 |
| h= 9 | 1.039 | 0.956 | 1.000 | 0.930 | 0.934 | 0.092 | 0.075 | 0.000 | 0.197 | -0.636 |
| h=12 | 1.003 | 0.938 | 1.000 | 0.924 | 0.923 | 0.225 | 0.201 | 0.000 | 0.300 | -0.564 |

The left half of this table reports the ratio between the multivariate weighted mean squared forecast error (WMSFE) of model i and the WMSFE of the benchmark BVAR model, computed as

$$WMSFE_{ih} = \frac{\sum_{\tau=\underline{t}}^{\bar{t}-h} we_{i,\tau+h}}{\sum_{\tau=\underline{t}}^{\bar{t}-h} we_{bcmk,\tau+h}},$$

where $we_{i,\tau+h} = (e'_{i,\tau+h} \times W \times e_{i,\tau+h})$ and $we_{bcmk,\tau+h} = (e'_{bcmk,\tau+h} \times W \times e_{bcmk,\tau+h})$ denote the weighted forecast errors of model i and the benchmark model at time $\tau+h$, $e_{i,\tau+h}$ and $e_{bcmk,\tau+h}$ are the $(N \times 1)$ vector of forecast errors, and W is an $(N \times N)$ matrix of weights. We set $N = 7$, to focus on the following key seven series, $\{PAYEMS, CPIAUCSL, FEDFUNDS, INDPRO, UNRATE, PPIFGS, GS10\}$. In addition, we set the matrix W to be a diagonal matrix featuring on the diagonal the inverse of the variances of the series to be forecast. \underline{t} and \bar{t} denote the start and end of the out-of-sample period, $i \in \{DFM, FAVAR, BVAR, BCVAR, BCVAR_c\}$, and $h \in \{1, 2, 3, 6, 9, 12\}$. The right half of the table shows the multivariate average log predictive likelihood differentials between model i and the benchmark BVAR model, computed as

$$MVALPL_{ih} = \frac{1}{\bar{t} - \underline{t} - h + 1} \sum_{\tau=\underline{t}}^{\bar{t}-h} (MVLPL_{i,\tau+h} - MVLPL_{bcmk,\tau+h}),$$

where $MVLPL_{i,\tau+h}$ and $MVLPL_{bcmk,\tau+h}$ denote the multivariate log predictive likelihoods of model i and the benchmark model at time $\tau+h$, and are computed under the assumption of joint normality. All forecasts are generated out-of-sample using recursive estimates of the models, with the out of sample period starting in 1987:07 and ending in 2014:12. Bold numbers indicate the lowest WMSFE and highest MVALPL across all models for any given VAR size - forecast horizon pair. * significance at the 10% level; ** significance at the 5% level; *** significance at the 1% level.

Table 9. Out-of-sample forecast performance: Multivariate results, alternative BIC

| <i>Fcst h.</i> | <i>Medium VAR</i> | | | | | | | | | |
|----------------|-------------------|--------------|-------------|-----------------|--------------------------|---------------|--------------|-----------------|-----------------|--------------------------|
| | <i>WMSFE</i> | | | | | <i>MVALPL</i> | | | | |
| | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> |
| h= 1 | 1.158 | 1.066 | 1.132 | 0.918*** | 0.930*** | 0.551*** | 0.770*** | 0.979*** | 0.906*** | 0.306*** |
| h= 2 | 1.051 | 1.052 | 1.115 | 0.927** | 0.933** | 0.832*** | 0.818*** | 1.068*** | 1.031*** | 0.382*** |
| h= 3 | 1.027 | 1.031 | 1.064 | 0.942* | 0.944* | 0.890*** | 0.874*** | 1.097*** | 1.048*** | 0.354*** |
| h= 6 | 1.027 | 0.992 | 1.017 | 0.955 | 0.955 | 0.868*** | 0.837*** | 1.030*** | 1.002*** | 0.279*** |
| h= 9 | 1.017 | 0.977 | 0.995 | 0.956 | 0.960 | 0.850*** | 0.858*** | 1.021*** | 0.976*** | 0.253*** |
| h=12 | 1.025 | 0.988 | 1.039 | 1.001 | 0.995 | 0.877*** | 0.867*** | 0.927*** | 0.923*** | 0.192*** |
| | <i>Large VAR</i> | | | | | | | | | |
| | <i>WMSFE</i> | | | | | <i>MVALPL</i> | | | | |
| | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> |
| h= 1 | 1.160 | 1.048 | 1.103 | 0.907*** | 0.941*** | 0.710*** | 0.820*** | 0.988*** | 0.919*** | 0.245*** |
| h= 2 | 1.117 | 1.033 | 1.148 | 0.921*** | 0.920*** | 0.847*** | 0.844*** | 0.895*** | 1.018*** | 0.346*** |
| h= 3 | 1.083 | 0.981 | 1.126 | 0.936** | 0.931*** | 0.886*** | 0.835*** | 0.945*** | 1.023*** | 0.275*** |
| h= 6 | 1.016 | 0.980** | 0.977 | 0.937** | 0.936** | 0.937*** | 0.828*** | 1.187*** | 1.064*** | 0.291*** |
| h= 9 | 0.999 | 0.994 | 0.979 | 0.946** | 0.947** | 0.935*** | 0.828*** | 1.198*** | 1.056*** | 0.248*** |
| h=12 | 1.009 | 0.993* | 1.026 | 0.974 | 0.967** | 0.886*** | 0.837*** | 1.017*** | 0.948*** | 0.176** |
| | <i>Huge VAR</i> | | | | | | | | | |
| | <i>WMSFE</i> | | | | | <i>MVALPL</i> | | | | |
| | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR</i> | <i>BCVAR_c</i> |
| h= 1 | 1.049 | 1.009 | 1.017 | 0.901*** | 0.925*** | 0.950*** | 0.935*** | 0.905*** | 1.001*** | 0.323*** |
| h= 2 | 1.037 | 0.996 | 1.053 | 0.905*** | 0.905*** | 1.053*** | 0.971*** | 0.944*** | 1.124*** | 0.390*** |
| h= 3 | 1.030 | 0.970 | 1.045 | 0.914** | 0.905** | 1.049*** | 0.999*** | 0.974*** | 1.139*** | 0.369*** |
| h= 6 | 1.063 | 0.955 | 1.026 | 0.934 | 0.927 | 0.957*** | 0.995*** | 0.830*** | 1.153*** | 0.306*** |
| h= 9 | 1.049 | 0.965 | 1.009 | 0.938 | 0.926* | 0.972*** | 0.954*** | 0.879*** | 1.089*** | 0.263*** |
| h=12 | 1.052 | 0.984 | 1.049 | 0.974 | 0.948 | 0.934*** | 0.910*** | 0.709** | 0.992*** | 0.144 |

The left half of this table reports the ratio between the multivariate weighted mean squared forecast error (WMSFE) of model i and the WMSFE of the benchmark AR(1) model, computed as

$$WMSFE_{ih} = \frac{\sum_{\tau=\underline{t}}^{\bar{t}-h} we_{i,\tau+h}}{\sum_{\tau=\underline{t}}^{\bar{t}-h} we_{bck,\tau+h}},$$

where $we_{i,\tau+h} = (e'_{i,\tau+h} \times W \times e_{i,\tau+h})$ and $we_{bck,\tau+h} = (e'_{bck,\tau+h} \times W \times e_{bck,\tau+h})$ denote the weighted forecast errors of model i and the benchmark model at time $\tau+h$, $e_{i,\tau+h}$ and $e_{bck,\tau+h}$ are the $(N \times 1)$ vector of forecast errors, and W is an $(N \times N)$ matrix of weights. We set $N = 7$, to focus on the following key seven series, $\{PAYEMS, CPIAUCSL, FEDFUNDS, INDPRO, UNRATE, PPIFGS, GS10\}$. In addition, we set the matrix W to be a diagonal matrix featuring on the diagonal the inverse of the variances of the series to be forecast. \underline{t} and \bar{t} denote the start and end of the out-of-sample period, $i \in \{DFM, FAVAR, BVAR, BCVAR, BCVAR_c\}$, and $h \in \{1, 2, 3, 6, 9, 12\}$. The right half of the table shows the multivariate average log predictive likelihood differentials between model i and the benchmark AR(1), computed as

$$MVALPL_{ih} = \frac{1}{\bar{t} - \underline{t} - h + 1} \sum_{\tau=\underline{t}}^{\bar{t}-h} (MVLPL_{i,\tau+h} - MVLPL_{bck,\tau+h}),$$

where $MVLPL_{i,\tau+h}$ and $MVLPL_{bck,\tau+h}$ denote the multivariate log predictive likelihoods of model i and the benchmark model at time $\tau+h$, and are computed under the assumption of joint normality. All forecasts are generated out-of-sample using recursive estimates of the models, with the out of sample period starting in 1987:07 and ending in 2014:12. Bold numbers indicate the lowest WMSFE and highest MVALPL across all models for any given VAR size - forecast horizon pair. * significance at the 10% level; ** significance at the 5% level; *** significance at the 1% level.

Table 10. Out-of-sample forecast performance: Multivariate results, 7 key variables ordered last

| $Fcst\ h.$ | <i>Medium VAR</i> | | | | | | | | | |
|------------|-------------------|--------------|-------------|--------------------------|------------------------------|-----------------|-----------------|-----------------|--------------------------|------------------------------|
| | <i>WMSFE</i> | | | | | <i>MVALPL</i> | | | | |
| | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR_c</i> | <i>BCVAR_{c,v,2}</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR_c</i> | <i>BCVAR_{c,v,2}</i> |
| h= 1 | 1.158 | 1.066 | 1.132 | 0.935*** | 0.935*** | 0.551*** | 0.770*** | 0.979*** | 0.285*** | 0.301*** |
| h= 2 | 1.051 | 1.052 | 1.115 | 0.926*** | 0.926*** | 0.832*** | 0.818*** | 1.068*** | 0.401*** | 0.403*** |
| h= 3 | 1.027 | 1.031 | 1.064 | 0.940* | 0.939** | 0.890*** | 0.874*** | 1.097*** | 0.356*** | 0.357*** |
| h= 6 | 1.027 | 0.992 | 1.017 | 0.954 | 0.956 | 0.868*** | 0.837*** | 1.030*** | 0.296*** | 0.279*** |
| h= 9 | 1.017 | 0.977 | 0.995 | 0.960 | 0.953 | 0.850*** | 0.858*** | 1.021*** | 0.254*** | 0.237*** |
| h=12 | 1.025 | 0.988 | 1.039 | 0.994 | 0.995 | 0.877*** | 0.867*** | 0.927*** | 0.176*** | 0.166** |
| | <i>Large VAR</i> | | | | | | | | | |
| | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR_c</i> | <i>BCVAR_{c,v,2}</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR_c</i> | <i>BCVAR_{c,v,2}</i> |
| h= 1 | 1.160 | 1.048 | 1.103 | 0.939*** | 0.936*** | 0.710*** | 0.820*** | 0.988*** | 0.253*** | 0.293*** |
| h= 2 | 1.117 | 1.033 | 1.148 | 0.924*** | 0.945*** | 0.847*** | 0.844*** | 0.895*** | 0.360*** | 0.313*** |
| h= 3 | 1.083 | 0.981 | 1.126 | 0.939*** | 0.957** | 0.886*** | 0.835*** | 0.945*** | 0.264*** | 0.267*** |
| h= 6 | 1.016 | 0.980** | 0.977 | 0.935** | 0.952** | 0.937*** | 0.828*** | 1.187*** | 0.276*** | 0.242*** |
| h= 9 | 0.999 | 0.994 | 0.979 | 0.951** | 0.965* | 0.935*** | 0.828*** | 1.198*** | 0.271*** | 0.264*** |
| h=12 | 1.009 | 0.993* | 1.026 | 0.965** | 0.977 | 0.886*** | 0.837*** | 1.017*** | 0.157* | 0.142 |
| | <i>Huge VAR</i> | | | | | | | | | |
| | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR_c</i> | <i>BCVAR_{c,v,2}</i> | <i>DFM</i> | <i>FAVAR</i> | <i>BVAR</i> | <i>BCVAR_c</i> | <i>BCVAR_{c,v,2}</i> |
| h= 1 | 1.049 | 1.009 | 1.017 | 0.940*** | 0.945*** | 0.950*** | 0.935*** | 0.905*** | 0.303*** | 0.304*** |
| h= 2 | 1.037 | 0.996 | 1.053 | 0.908*** | 0.940* | 1.053*** | 0.971*** | 0.944*** | 0.406*** | 0.371*** |
| h= 3 | 1.030 | 0.970 | 1.045 | 0.922** | 0.947 | 1.049*** | 0.999*** | 0.974*** | 0.368*** | 0.317*** |
| h= 6 | 1.063 | 0.955 | 1.026 | 0.940 | 0.953 | 0.957*** | 0.995*** | 0.830*** | 0.269*** | 0.267*** |
| h= 9 | 1.049 | 0.965 | 1.009 | 0.943 | 0.961 | 0.972*** | 0.954*** | 0.879*** | 0.243*** | 0.217** |
| h=12 | 1.052 | 0.984 | 1.049 | 0.968 | 0.973 | 0.934*** | 0.910*** | 0.709** | 0.145 | 0.143* |

The left half of this table reports the ratio between the multivariate weighted mean squared forecast error (WMSFE) of model i and the WMSFE of the benchmark AR(1) model, computed as

$$WMSFE_{ih} = \frac{\sum_{\tau=\underline{t}}^{\bar{t}-h} we_{i,\tau+h}}{\sum_{\tau=\underline{t}}^{\bar{t}-h} we_{bckm,\tau+h}},$$

where $we_{i,\tau+h} = (e'_{i,\tau+h} \times W \times e_{i,\tau+h})$ and $we_{bckm,\tau+h} = (e'_{bckm,\tau+h} \times W \times e_{bckm,\tau+h})$ denote the weighted forecast errors of model i and the benchmark model at time $\tau+h$, $e_{i,\tau+h}$ and $e_{bckm,\tau+h}$ are the $(N \times 1)$ vector of forecast errors, and W is an $(N \times N)$ matrix of weights. We set $N = 7$, to focus on the following key seven series, $\{PAYEMS, CPIAUCSL, FEDFUNDS, INDPRO, UNRATE, PPIFGS, GS10\}$. In addition, we set the matrix W to be a diagonal matrix featuring on the diagonal the inverse of the variances of the series to be forecast. \underline{t} and \bar{t} denote the start and end of the out-of-sample period, $i \in \{DFM, FAVAR, BVAR, BCVAR_c, BCVAR_{c,v,2}\}$, and $h \in \{1, 2, 3, 6, 9, 12\}$. The right half of the table shows the multivariate average log predictive likelihood differentials between model i and the benchmark AR(1), computed as

$$MVALPL_{ih} = \frac{1}{\bar{t} - \underline{t} - h + 1} \sum_{\tau=\underline{t}}^{\bar{t}-h} (MVLPL_{i,\tau+h} - MVLPL_{bckm,\tau+h}),$$

where $MVLPL_{i,\tau+h}$ and $MVLPL_{bckm,\tau+h}$ denote the multivariate log predictive likelihoods of model i and the benchmark model at time $\tau+h$, and are computed under the assumption of joint normality. All forecasts are generated out-of-sample using recursive estimates of the models, with the out of sample period starting in 1987:07 and ending in 2014:12. Bold numbers indicate the lowest WMSFE and highest MVALPL across all models for any given VAR size - forecast horizon pair. * significance at the 10% level; ** significance at the 5% level; *** significance at the 1% level.

Table 11. Out-of-sample forecast performance: Compressed TVP-SV VAR

| Variable | Medium VAR | | | | | | | | | | | |
|--------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| | MSFE | | | | | | ALPL | | | | | |
| | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ |
| PAYEMS | 0.700*** | 0.565*** | 0.565*** | 0.651** | 0.769* | 0.872 | 0.338*** | 0.391*** | 0.352*** | 0.078 | -0.422 | -0.533 |
| CPIAUCSL | 0.924** | 0.872*** | 0.884*** | 0.869** | 0.841*** | 0.845*** | 0.284* | 0.211*** | 0.461 | 0.191 | 0.280 | 0.292 |
| FEDFUNDS | 0.879* | 0.892 | 0.924 | 0.995 | 0.967 | 1.061 | 0.760*** | 0.594** | 0.423 | 0.382 | 0.303 | 0.365 |
| INDPRO | 0.899*** | 0.925* | 0.940 | 0.978 | 0.980 | 0.989 | -0.030 | -0.224 | -0.128 | -0.509 | -0.414 | -0.255 |
| UNRATE | 0.846*** | 0.847** | 0.876* | 0.939 | 0.971 | 1.011 | 0.123*** | 0.104*** | 0.095*** | 0.059*** | 0.036 | -0.009 |
| PPIFGS | 0.968 | 0.991 | 1.001 | 0.998 | 0.992 | 1.010 | 0.270* | 0.349 | 0.401 | 0.283 | 0.407 | 0.354 |
| GS10 | 1.018 | 1.017 | 1.039 | 1.030 | 0.995 | 1.030 | 0.025 | -0.016 | -0.053 | -0.057 | -0.004 | 0.030 |
| Multivariate | 0.905*** | 0.884*** | 0.892*** | 0.916* | 0.924* | 0.967 | 1.653*** | 1.701*** | 1.573*** | 1.224*** | 1.049*** | 0.851*** |
| Variable | Large VAR | | | | | | | | | | | |
| | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ |
| | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ |
| PAYEMS | 0.699*** | 0.566*** | 0.565*** | 0.648** | 0.739** | 0.837 | 0.326*** | 0.387*** | 0.335*** | -0.064 | -0.508 | -0.929 |
| CPIAUCSL | 0.939 | 0.870*** | 0.862*** | 0.843*** | 0.796*** | 0.809*** | 0.257 | 0.486 | 0.306 | 0.244 | 0.345 | 0.181 |
| FEDFUNDS | 0.875** | 0.847** | 0.843** | 0.932 | 0.968 | 1.033 | 0.838*** | 0.616** | 0.531* | 0.380 | 0.073 | 0.307 |
| INDPRO | 0.904*** | 0.930* | 0.936* | 0.962 | 0.983 | 0.982 | -0.079 | -0.085 | -0.189 | -0.348 | -0.290 | -0.399 |
| UNRATE | 0.862*** | 0.863*** | 0.899** | 0.926** | 0.959** | 0.984 | 0.104*** | 0.104*** | 0.078*** | 0.052*** | 0.031 | -0.013 |
| PPIFGS | 0.972 | 0.985 | 0.983 | 0.987 | 0.958 | 0.976 | 0.285 | 0.400 | 0.371 | 0.361 | 0.379 | 0.359 |
| GS10 | 1.013 | 1.007 | 1.037 | 1.023 | 1.012 | 1.021 | 0.015 | 0.009 | -0.049 | -0.008 | -0.013 | -0.001 |
| Multivariate | 0.910*** | 0.878*** | 0.877*** | 0.896*** | 0.908*** | 0.941** | 1.633*** | 1.635*** | 1.511*** | 1.215*** | 0.966*** | 0.674 |
| Variable | Huge VAR | | | | | | | | | | | |
| | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ |
| | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ |
| PAYEMS | 0.685*** | 0.566*** | 0.548*** | 0.656* | 0.762 | 0.879 | 0.338*** | 0.405*** | 0.374*** | 0.083 | -0.447 | -0.530 |
| CPIAUCSL | 0.904** | 0.846*** | 0.844*** | 0.848** | 0.800*** | 0.796*** | 0.241 | 0.364* | 0.361 | 0.354 | 0.539 | 0.074 |
| FEDFUNDS | 0.885 | 0.911 | 0.920 | 1.022 | 1.034 | 1.075 | 0.715*** | 0.577* | 0.489 | 0.445 | 0.100 | 0.269 |
| INDPRO | 0.896*** | 0.928 | 0.957 | 0.996 | 1.002 | 1.020 | 0.116** | 0.036 | -0.184 | -0.320 | -0.205 | -0.210 |
| UNRATE | 0.836*** | 0.851** | 0.880* | 0.949 | 0.981 | 1.026 | 0.122*** | 0.102*** | 0.078*** | 0.050** | 0.034 | 0.010 |
| PPIFGS | 0.983 | 0.985 | 1.005 | 1.008 | 0.995 | 1.012 | 0.254* | 0.363 | 0.371 | 0.346 | 0.385 | 0.213 |
| GS10 | 1.021 | 1.021 | 1.034 | 1.024 | 1.013 | 1.021 | 0.008 | 0.037** | 0.017 | 0.008 | 0.029 | -0.033 |
| Multivariate | 0.902*** | 0.883*** | 0.885** | 0.922 | 0.932 | 0.967 | 1.667*** | 1.666*** | 1.593*** | 1.216*** | 1.002*** | 0.713* |

The left half of this table reports the ratio between the univariate or multivariate weighted mean squared forecast error of the $BCVAR_{tvp-sv}$ model and the univariate or multivariate weighted mean squared forecast error of the benchmark AR(1) model. The right half of the table shows the univariate or multivariate average log predictive likelihood differentials between the $BCVAR_{tvp-sv}$ model and the benchmark AR(1) model. h denotes the forecast horizons, with $h \in \{1, 2, 3, 6, 9, 12\}$. All forecasts are generated out-of-sample using recursive estimates of the models, with the out of sample period starting in 1987:07 and ending in 2014:12. Bold numbers indicate all instances where the $BCVAR_{tvp-sv}$ model outperforms all alternative models (DFM , $FAVAR$, $BVAR$, $BCVAR$, $BCVAR_c$), for any given VAR size/variable/forecast horizon combination. * significance at the 10% level; ** significance at the 5% level; *** significance at the 1% level.

Table 12. Out-of-sample forecast performance: Compressed TVP-SV VAR, BVAR as the benchmark

| Variable | Medium VAR | | | | | | | | | | | |
|--------------|-----------------|-----------------|-----------------|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|---------------|--------------|--------------|
| | MSFE | | | | | | ALPL | | | | | |
| | $h = 1$ | $h = 2$ | $h = 3$ | $h = 6$ | $h = 9$ | $h = 12$ | $h = 1$ | $h = 2$ | $h = 3$ | $h = 6$ | $h = 9$ | $h = 12$ |
| PAYEMS | 0.810** | 1.020 | 1.082 | 0.948 | 0.933 | 0.937 | 0.120*** | 0.025 | -0.012 | -0.167 | -0.514 | -0.573 |
| CPIAUCSL | 0.973 | 0.873** | 0.848*** | 0.823** | 0.811*** | 0.790*** | 0.959 | 1.880 | 1.444 | 1.051 | 1.026 | 1.197 |
| FEDFUNDS | 0.319*** | 0.364*** | 0.497** | 0.833* | 0.975 | 0.985 | 0.629*** | 0.479* | 0.308 | 0.263 | 0.184 | 0.256 |
| INDPRO | 1.109 | 1.121 | 1.009 | 0.956 | 0.957 | 0.985 | 0.068 | -0.175 | -0.127 | -0.281 | -0.262 | -0.237 |
| UNRATE | 1.081 | 1.053 | 1.031 | 0.992 | 0.999 | 1.003 | -0.043 | -0.026 | -0.014 | 0.001 | -0.003 | -0.042 |
| PPIFGS | 0.987 | 0.914* | 0.908*** | 0.879* | 0.889* | 0.886* | 0.718** | 1.074 | 0.884* | 1.091 | 0.820 | 0.744 |
| GS10 | 0.932 | 0.941 | 0.912 | 0.924 | 0.971 | 0.979 | 0.011 | -0.007 | -0.063 | -0.060 | -0.046 | 0.020 |
| Multivariate | 0.800*** | 0.793*** | 0.838** | 0.901* | 0.928** | 0.931** | 0.674*** | 0.634*** | 0.476*** | 0.194 | 0.028 | -0.077 |
| | Large VAR | | | | | | | | | | | |
| | $h = 1$ | $h = 2$ | $h = 3$ | $h = 6$ | $h = 9$ | $h = 12$ | $h = 1$ | $h = 2$ | $h = 3$ | $h = 6$ | $h = 9$ | $h = 12$ |
| | $h = 1$ | $h = 2$ | $h = 3$ | $h = 6$ | $h = 9$ | $h = 12$ | $h = 1$ | $h = 2$ | $h = 3$ | $h = 6$ | $h = 9$ | $h = 12$ |
| PAYEMS | 0.883 | 1.106 | 1.211 | 1.072 | 0.970 | 0.909 | 0.072** | -0.019 | -0.081 | -0.364 | -0.674 | -0.992 |
| CPIAUCSL | 0.939 | 0.791* | 0.752* | 0.853* | 0.875** | 0.900* | 1.043** | 2.586 | 2.179 | 1.070 | 1.217 | 0.902 |
| FEDFUNDS | 0.357*** | 0.334** | 0.388** | 0.755** | 0.821** | 0.806* | 0.692*** | 0.642** | 0.502 | 0.221 | -0.072 | 0.174 |
| INDPRO | 1.162 | 1.206 | 1.098 | 0.981 | 0.981 | 0.942 | -0.041 | -0.266 | -0.133 | -0.033 | -0.113 | -0.211 |
| UNRATE | 1.118 | 1.087 | 1.070 | 1.044 | 0.994 | 0.981 | -0.066 | -0.046 | -0.041 | -0.040 | -0.019 | -0.030 |
| PPIFGS | 0.935 | 0.845* | 0.842** | 0.907 | 0.913* | 0.937* | 0.963*** | 1.505* | 1.458* | 1.152 | 1.026 | 0.908 |
| GS10 | 0.910 | 0.902 | 0.856*** | 0.932** | 0.971 | 0.979 | 0.041 | -0.007 | -0.021 | -0.011 | -0.047 | -0.030 |
| Multivariate | 0.825*** | 0.765*** | 0.779** | 0.918** | 0.927** | 0.917** | 0.645*** | 0.739*** | 0.566** | 0.027 | -0.232 | -0.344 |
| | Huge VAR | | | | | | | | | | | |
| | $h = 1$ | $h = 2$ | $h = 3$ | $h = 6$ | $h = 9$ | $h = 12$ | $h = 1$ | $h = 2$ | $h = 3$ | $h = 6$ | $h = 9$ | $h = 12$ |
| | $h = 1$ | $h = 2$ | $h = 3$ | $h = 6$ | $h = 9$ | $h = 12$ | $h = 1$ | $h = 2$ | $h = 3$ | $h = 6$ | $h = 9$ | $h = 12$ |
| PAYEMS | 0.915 | 1.177 | 1.157 | 1.059 | 1.026 | 1.010 | 0.036 | -0.066 | -0.073 | -0.213 | -0.574 | -0.607 |
| CPIAUCSL | 1.052 | 0.907* | 0.863** | 0.813** | 0.783** | 0.768* | 0.603* | 2.482 | 2.656 | 2.539 | 1.534 | 1.735 |
| FEDFUNDS | 0.429*** | 0.418*** | 0.505** | 0.771* | 0.928 | 0.934 | 0.424** | 0.330 | 0.261 | 0.258 | -0.175 | 0.058 |
| INDPRO | 1.152 | 1.159 | 1.072 | 0.974 | 0.938 | 0.950 | 0.427 | 0.094 | -0.249 | -0.169 | -0.022 | -0.036 |
| UNRATE | 1.050 | 1.106 | 1.053 | 1.071 | 1.045 | 1.044 | -0.003 | -0.061 | -0.028 | -0.034 | -0.011 | -0.024 |
| PPIFGS | 1.048 | 0.927 | 0.923** | 0.875** | 0.866** | 0.856* | 1.282** | 2.176* | 1.686* | 1.940 | 1.612 | 0.937 |
| GS10 | 0.926 | 0.899 | 0.850** | 0.868** | 0.943 | 0.944 | 0.001 | 0.046 | 0.044 | 0.033 | -0.010 | -0.067 |
| Multivariate | 0.887*** | 0.838*** | 0.847** | 0.899* | 0.923** | 0.922* | 0.761*** | 0.722** | 0.618** | 0.386* | 0.123 | 0.004 |

The left half of this table reports the ratio between the univariate or multivariate weighted mean squared forecast error of the $BCVAR_{tvp-sv}$ model and the univariate or multivariate weighted mean squared forecast error of the benchmark BVAR model. The right half of the table shows the univariate or multivariate average log predictive likelihood differentials between the $BCVAR_{tvp-sv}$ model and the benchmark BVAR model. h denotes the forecast horizons, with $h \in \{1, 2, 3, 6, 9, 12\}$. All forecasts are generated out-of-sample using recursive estimates of the models, with the out of sample period starting in 1987:07 and ending in 2014:12. Bold numbers indicate all instances where the $BCVAR_{tvp-sv}$ model outperforms all alternative models (DFM , $FAVAR$, $BVAR$, $BCVAR$, $BCVAR_c$), for any given VAR size/variable/forecast horizon combination. * significance at the 10% level; ** significance at the 5% level; *** significance at the 1% level.

Table 13. Out-of-sample forecast performance: Compressed TVP-SV VAR, alternative BIC

| Variable | Medium VAR | | | | | | | | | | | |
|--------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|---------------|
| | MSFE | | | | | | ALPL | | | | | |
| | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ |
| PAYEMS | 0.742*** | 0.586*** | 0.572*** | 0.646** | 0.773* | 0.890 | 0.323*** | 0.384*** | 0.324*** | -0.032 | -0.557 | -0.759 |
| CPIAUCSL | 0.919*** | 0.874*** | 0.889*** | 0.860** | 0.836*** | 0.850*** | 0.278* | 0.247** | 0.416 | 0.159* | 0.270 | 0.190* |
| FEDFUNDS | 0.889 | 0.872 | 0.947 | 1.024 | 1.001 | 1.106 | 0.601** | 0.635** | 0.539* | 0.320 | 0.321 | 0.193 |
| INDPRO | 0.911** | 0.933 | 0.974 | 0.981 | 0.992 | 0.991 | -0.021 | -0.100 | -0.170 | -0.614 | -0.477 | -0.186 |
| UNRATE | 0.839*** | 0.847** | 0.885* | 0.937 | 0.982 | 1.020 | 0.113*** | 0.105*** | 0.086*** | 0.051** | 0.038 | -0.002 |
| PPIFGS | 0.985 | 0.995 | 1.014 | 0.998 | 0.996 | 1.012 | 0.277** | 0.348 | 0.386 | 0.334 | 0.369 | 0.324 |
| GS10 | 1.022 | 1.033 | 1.047 | 1.036 | 1.012 | 1.038 | 0.007 | -0.009 | -0.089 | -0.049 | -0.016 | -0.059 |
| Multivariate | 0.913*** | 0.888*** | 0.906** | 0.919* | 0.934 | 0.979 | 1.581*** | 1.703*** | 1.527*** | 1.144*** | 1.008*** | 0.819** |
| | Large VAR | | | | | | | | | | | |
| | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ |
| | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ |
| PAYEMS | 0.741*** | 0.586*** | 0.594*** | 0.655*** | 0.736** | 0.848 | 0.313*** | 0.386*** | 0.251** | -0.149 | -0.614 | -0.957 |
| CPIAUCSL | 0.943 | 0.869*** | 0.873*** | 0.844*** | 0.782*** | 0.819*** | 0.224 | 0.427 | 0.326 | 0.316 | 0.193*** | 0.247 |
| FEDFUNDS | 0.878** | 0.853** | 0.852* | 0.957 | 0.986 | 1.065 | 0.689*** | 0.655*** | 0.633*** | 0.562*** | 0.214 | 0.397 |
| INDPRO | 0.920*** | 0.928** | 0.933* | 0.969 | 0.959 | 0.984 | 0.069 | -0.124 | -0.174 | -0.389 | -0.258 | -0.301 |
| UNRATE | 0.870*** | 0.898** | 0.915** | 0.925** | 0.971 | 0.986 | 0.105*** | 0.092*** | 0.080*** | 0.051*** | 0.017 | -0.009 |
| PPIFGS | 0.974 | 1.005 | 0.986 | 0.970 | 0.962 | 0.979 | 0.258 | 0.363 | 0.338 | 0.361 | 0.355 | 0.311 |
| GS10 | 1.017 | 1.021 | 1.045 | 1.017 | 1.014 | 1.012 | -0.013 | -0.038 | -0.048 | -0.049 | 0.006 | -0.034 |
| Multivariate | 0.919*** | 0.891*** | 0.887*** | 0.899*** | 0.907*** | 0.949** | 1.569*** | 1.572*** | 1.457*** | 1.160*** | 0.972*** | 0.711* |
| | Huge VAR | | | | | | | | | | | |
| | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ |
| | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ |
| PAYEMS | 0.718*** | 0.569*** | 0.557*** | 0.658* | 0.768 | 0.879 | 0.329*** | 0.396*** | 0.340*** | 0.069 | -0.279 | -0.547 |
| CPIAUCSL | 0.923* | 0.858*** | 0.862*** | 0.863* | 0.816*** | 0.811*** | 0.260* | 0.431* | 0.442 | 0.347 | 0.409 | 0.248 |
| FEDFUNDS | 0.904 | 0.891 | 0.905 | 1.007 | 1.016 | 1.074 | 0.648** | 0.642** | 0.447 | 0.469 | 0.322 | 0.290 |
| INDPRO | 0.908*** | 0.929* | 0.940 | 1.003 | 1.016 | 1.016 | -0.038 | -0.204 | -0.043 | -0.252 | -0.250 | -0.400 |
| UNRATE | 0.850*** | 0.868* | 0.901 | 0.961 | 0.978 | 1.027 | 0.115*** | 0.096*** | 0.076*** | 0.053** | 0.035 | 0.007 |
| PPIFGS | 0.980 | 1.002 | 0.997 | 1.001 | 1.004 | 1.018 | 0.250* | 0.344 | 0.370 | 0.329 | 0.403 | 0.228 |
| GS10 | 1.023 | 1.032 | 1.036 | 1.044 | 1.018 | 1.018 | -0.002 | 0.003 | -0.005 | -0.025 | 0.011 | -0.022 |
| Multivariate | 0.914*** | 0.889*** | 0.887** | 0.927 | 0.937 | 0.969 | 1.629*** | 1.690*** | 1.562*** | 1.224*** | 1.023*** | 0.700* |

The left half of this table reports the ratio between the univariate or multivariate weighted mean squared forecast error of the $BCVAR_{tvp-sv}$ model and the univariate or multivariate weighted mean squared forecast error of the benchmark AR(1) model. The right half of the table shows the univariate or multivariate average log predictive likelihood differentials between the $BCVAR_{tvp-sv}$ model and the benchmark AR(1) model. h denotes the forecast horizons, with $h \in \{1, 2, 3, 6, 9, 12\}$. All forecasts are generated out-of-sample using recursive estimates of the models, with the out of sample period starting in 1987:07 and ending in 2014:12. Bold numbers indicate all instances where the $BCVAR_{tvp-sv}$ model outperforms all alternative models (DFM , $FAVAR$, $BVAR$, $BCVAR$, $BCVAR_c$), for any given VAR size/variable/forecast horizon combination. * significance at the 10% level; ** significance at the 5% level; *** significance at the 1% level.

Table 14. Out-of-sample forecast performance: Compressed TVP-SV VAR, 7 key variables ordered last

| Variable | Medium VAR | | | | | | | | | | | |
|--------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|----------------|--------------|
| | MSFE | | | | | | ALPL | | | | | |
| | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ |
| PAYEMS | 0.727*** | 0.584*** | 0.564*** | 0.658** | 0.775* | 0.878 | 0.322*** | 0.380*** | 0.337*** | 0.043 | -0.351 | -0.546 |
| CPIAUCSL | 0.906*** | 0.875*** | 0.871*** | 0.861*** | 0.830*** | 0.853*** | 0.259* | 0.327** | 0.442 | 0.138** | 0.317* | 0.117 |
| FEDFUNDS | 0.906 | 0.872 | 0.922 | 0.997 | 0.969 | 1.050 | 0.699*** | 0.480 | 0.560** | 0.447 | 0.105 | 0.263 |
| INDPRO | 0.891*** | 0.929* | 0.934 | 0.967 | 0.991 | 0.988 | -0.045 | -0.177 | -0.264 | -0.480 | -0.443 | -0.196 |
| UNRATE | 0.872*** | 0.879* | 0.895* | 0.961 | 0.968 | 1.003 | 0.105*** | 0.095*** | 0.087*** | 0.054*** | 0.047** | 0.010 |
| PPIFGS | 0.979 | 0.994 | 0.990 | 0.995 | 0.999 | 1.006 | 0.282** | 0.351 | 0.388 | 0.323 | 0.390 | 0.323 |
| GS10 | 1.012 | 1.023 | 1.032 | 1.013 | 0.993 | 1.022 | -0.039 | -0.009 | -0.021 | -0.060 | 0.019 | -0.010 |
| Multivariate | 0.912*** | 0.891*** | 0.889*** | 0.915* | 0.925* | 0.965 | 1.634*** | 1.659*** | 1.566*** | 1.173*** | 0.990*** | 0.799** |
| | Large VAR | | | | | | | | | | | |
| | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ |
| | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ |
| PAYEMS | 0.771*** | 0.600*** | 0.591*** | 0.644** | 0.748** | 0.868 | 0.301*** | 0.360*** | 0.292*** | 0.128 | -0.340 | -0.969 |
| CPIAUCSL | 0.949 | 0.882*** | 0.874*** | 0.849*** | 0.805*** | 0.813*** | 0.251* | 0.456 | 0.342 | 0.284 | 0.273 | 0.227 |
| FEDFUNDS | 0.893** | 0.834** | 0.862* | 0.937 | 1.024 | 1.042 | 0.840*** | 0.700*** | 0.528* | 0.439 | 0.072 | 0.203 |
| INDPRO | 0.895*** | 0.962 | 0.975 | 0.988 | 0.989 | 1.004 | 0.028 | -0.005 | -0.110 | -0.359 | -0.258 | -0.278 |
| UNRATE | 0.873*** | 0.899** | 0.946 | 0.935** | 0.970 | 1.004 | 0.098*** | 0.089*** | 0.056** | 0.038* | 0.014 | -0.003 |
| PPIFGS | 0.961 | 0.978 | 0.970 | 0.954 | 0.947** | 0.977 | 0.274 | 0.404 | 0.390 | 0.342 | 0.375 | 0.289 |
| GS10 | 1.012 | 1.045 | 1.041 | 1.029 | 1.011 | 1.005 | 0.041** | 0.010 | -0.052 | 0.008 | -0.019 | -0.010 |
| Multivariate | 0.918*** | 0.897*** | 0.895*** | 0.899*** | 0.919** | 0.952* | 1.602*** | 1.551*** | 1.458*** | 1.167*** | 0.910*** | 0.674* |
| | Huge VAR | | | | | | | | | | | |
| | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ |
| | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ | $h=1$ | $h=2$ | $h=3$ | $h=6$ | $h=9$ | $h=12$ |
| PAYEMS | 0.724*** | 0.601*** | 0.566*** | 0.683* | 0.785 | 0.898 | 0.310*** | 0.384*** | 0.338*** | 0.091 | -0.259 | -0.504 |
| CPIAUCSL | 0.931* | 0.864*** | 0.903** | 0.859** | 0.795*** | 0.813*** | 0.229 | 0.348* | 0.307 | 0.300 | 0.347 | 0.154 |
| FEDFUNDS | 0.959 | 0.929 | 0.938 | 1.020 | 1.028 | 1.085 | 0.628** | 0.574** | 0.523 | 0.513* | 0.367 | -0.220 |
| INDPRO | 0.904** | 0.969 | 0.955 | 1.041 | 1.015 | 1.038 | 0.162* | -0.133 | -0.167 | -0.158 | -0.349 | -0.338 |
| UNRATE | 0.876** | 0.879* | 0.900 | 0.947 | 1.020 | 1.013 | 0.103*** | 0.087*** | 0.081*** | 0.048** | -0.006 | 0.018 |
| PPIFGS | 0.973 | 1.021 | 0.990 | 1.027 | 0.977 | 1.003 | 0.219 | 0.331 | 0.360 | 0.265 | 0.386 | 0.251 |
| GS10 | 1.028 | 1.039 | 1.062 | 1.045 | 1.021 | 1.043 | 0.001 | 0.016 | -0.057 | -0.035 | -0.090 | -0.042 |
| Multivariate | 0.925*** | 0.910*** | 0.904** | 0.939 | 0.940 | 0.977 | 1.554*** | 1.570*** | 1.485*** | 1.138*** | 0.910*** | 0.714** |

The left half of this table reports the ratio between the univariate or multivariate weighted mean squared forecast error of the $BCVAR_{tvp-sv}$ model and the univariate or multivariate weighted mean squared forecast error of the benchmark AR(1) model. The right half of the table shows the univariate or multivariate average log predictive likelihood differentials between the $BCVAR_{tvp-sv}$ model and the benchmark AR(1) model. h denotes the forecast horizons, with $h \in \{1, 2, 3, 6, 9, 12\}$. All forecasts are generated out-of-sample using recursive estimates of the models, with the out of sample period starting in 1987:07 and ending in 2014:12. Bold numbers indicate all instances where the $BCVAR_{tvp-sv}$ model outperforms all alternative models (DFM , $FAVAR$, $BVAR$, $BCVAR$, $BCVAR_c$), for any given VAR size/variable/forecast horizon combination. * significance at the 10% level; ** significance at the 5% level; *** significance at the 1% level.

Table 15. Out-of-sample forecast performance: Multivariate results, alternative SV models

| <i>Fest h.</i> | <i>Small VAR</i> | | | | | |
|----------------|---------------------------|---------------------------|-------------------------------|---------------------------|---------------------------|-------------------------------|
| | <i>WMSFE</i> | | | <i>MVALPL</i> | | |
| | <i>BVAR_{ccm}</i> | <i>BCVAR_{sv}</i> | <i>BCVAR_{tvp-sv}</i> | <i>BVAR_{ccm}</i> | <i>BCVAR_{sv}</i> | <i>BCVAR_{tvp-sv}</i> |
| h= 1 | 0.917*** | 0.942*** | 0.918*** | 2.047*** | 1.696*** | 1.719*** |
| h= 2 | 0.930*** | 0.944*** | 0.895*** | 1.907*** | 1.654*** | 1.745*** |
| h= 3 | 0.936*** | 0.951** | 0.901*** | 1.845*** | 1.563*** | 1.645*** |
| h= 6 | 0.946*** | 0.971 | 0.912*** | 1.608*** | 1.228*** | 1.386*** |
| h= 9 | 0.968*** | 0.981 | 0.936*** | 1.385*** | 0.978*** | 1.143*** |
| h=12 | 0.992 | 0.999 | 0.960* | 0.931* | 0.811* | 0.930*** |
| | <i>Medium VAR</i> | | | | | |
| | <i>BVAR_{ccm}</i> | <i>BCVAR_{sv}</i> | <i>BCVAR_{tvp-sv}</i> | <i>BVAR_{ccm}</i> | <i>BCVAR_{sv}</i> | <i>BCVAR_{tvp-sv}</i> |
| h= 1 | 1.070 | 0.935*** | 0.905*** | 1.599*** | 1.522*** | 1.653*** |
| h= 2 | 1.089 | 0.922*** | 0.884*** | 1.521*** | 1.558*** | 1.701*** |
| h= 3 | 1.123 | 0.931** | 0.892*** | 1.236*** | 1.399*** | 1.573*** |
| h= 6 | 1.125 | 0.937* | 0.916* | 1.041*** | 1.129*** | 1.224*** |
| h= 9 | 1.031 | 0.947* | 0.924* | 1.078*** | 0.938*** | 1.049*** |
| h=12 | 1.007 | 0.981 | 0.967 | 1.039*** | 0.760** | 0.851*** |
| | <i>Large VAR</i> | | | | | |
| | <i>BVAR_{ccm}</i> | <i>BCVAR_{sv}</i> | <i>BCVAR_{tvp-sv}</i> | <i>BVAR_{ccm}</i> | <i>BCVAR_{sv}</i> | <i>BCVAR_{tvp-sv}</i> |
| h= 1 | | 0.942*** | 0.910*** | | 1.520*** | 1.633*** |
| h= 2 | | 0.924*** | 0.878*** | | 1.512*** | 1.635*** |
| h= 3 | | 0.927*** | 0.877*** | | 1.324*** | 1.511*** |
| h= 6 | | 0.919** | 0.896*** | | 1.119*** | 1.215*** |
| h= 9 | | 0.932** | 0.908*** | | 0.895*** | 0.966*** |
| h=12 | | 0.959** | 0.941** | | 0.718* | 0.674 |
| | <i>Huge VAR</i> | | | | | |
| | <i>BVAR_{ccm}</i> | <i>BCVAR_{sv}</i> | <i>BCVAR_{tvp-sv}</i> | <i>BVAR_{ccm}</i> | <i>BCVAR_{sv}</i> | <i>BCVAR_{tvp-sv}</i> |
| h= 1 | | 0.942*** | 0.902*** | | 1.488*** | 1.667*** |
| h= 2 | | 0.924** | 0.883*** | | 1.543*** | 1.666*** |
| h= 3 | | 0.919** | 0.885** | | 1.394*** | 1.593*** |
| h= 6 | | 0.939 | 0.922 | | 1.118*** | 1.216*** |
| h= 9 | | 0.938 | 0.932 | | 0.894*** | 1.002*** |
| h=12 | | 0.950 | 0.967 | | 0.722* | 0.713* |

The left half of this table reports the ratio between the multivariate weighted mean squared forecast error (WMSFE) of model i and the WMSFE of the benchmark AR(1) model, computed as

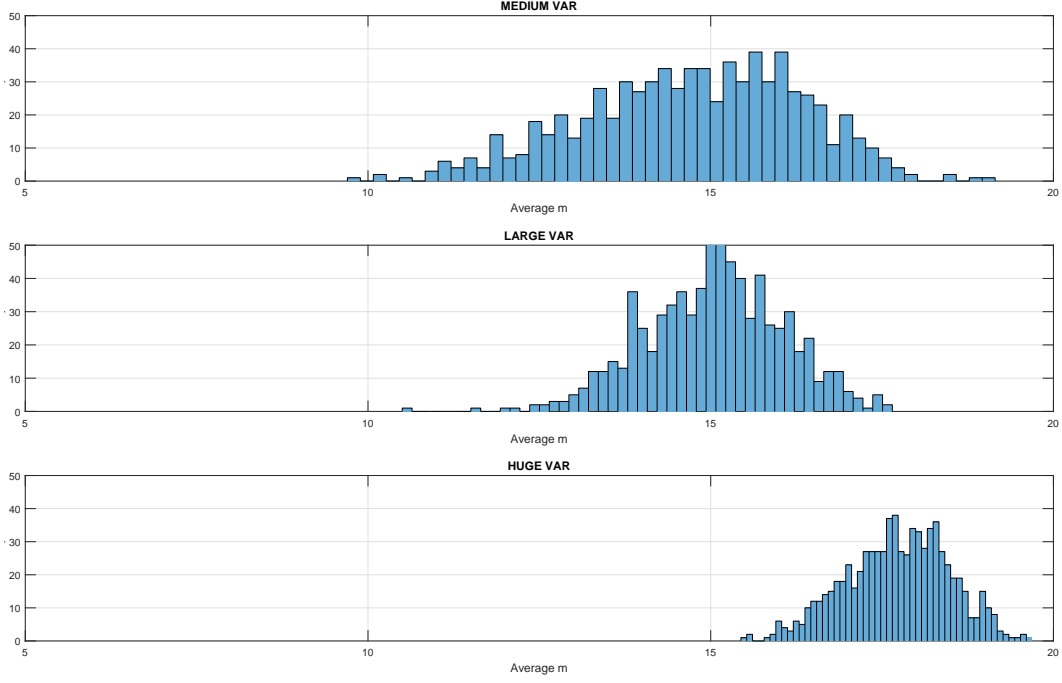
$$WMSFE_{ih} = \frac{\sum_{\tau=\underline{t}}^{\bar{t}-h} we_{i,\tau+h}}{\sum_{\tau=\underline{t}}^{\bar{t}-h} we_{bckm,\tau+h}},$$

where $we_{i,\tau+h} = (e'_{i,\tau+h} \times W \times e_{i,\tau+h})$ and $we_{bckm,\tau+h} = (e'_{bckm,\tau+h} \times W \times e_{bckm,\tau+h})$ denote the weighted forecast errors of model i and the benchmark model at time $\tau+h$, $e_{i,\tau+h}$ and $e_{bckm,\tau+h}$ are the $(N \times 1)$ vector of forecast errors, and W is an $(N \times N)$ matrix of weights. We set $N = 7$, to focus on the following key seven series, $\{PAYEMS, CPIAUCSL, FEDFUNDS, INDPRO, UNRATE, PPIFGS, GS10\}$. In addition, we set the matrix W to be a diagonal matrix featuring on the diagonal the inverse of the variances of the series to be forecast. \underline{t} and \bar{t} denote the start and end of the out-of-sample period, $i \in \{BVAR_{ccm}, BCVAR_{sv}, BCVAR_{tvp-sv}\}$, and $h \in \{1, 2, 3, 6, 9, 12\}$. The right half of the table shows the multivariate average log predictive likelihood differentials between model i and the benchmark AR(1), computed as

$$MVALPL_{ih} = \frac{1}{\bar{t} - \underline{t} - h + 1} \sum_{\tau=\underline{t}}^{\bar{t}-h} (MVLPL_{i,\tau+h} - MVLPL_{bckm,\tau+h}),$$

where $MVLPL_{i,\tau+h}$ and $MVLPL_{bckm,\tau+h}$ denote the multivariate log predictive likelihoods of model i and the benchmark model at time $\tau+h$, and are computed under the assumption of joint normality. All forecasts are generated out-of-sample using recursive estimates of the models, with the out of sample period starting in 1987:07 and ending in 2014:12. Bold numbers indicate the lowest WMSFE and highest MVALPL across all models for any given VAR size - forecast horizon pair. * significance at the 10% level; ** significance at the 5% level; *** significance at the 1% level.

Figure 1. Average compression size (m) for top 75% compressions

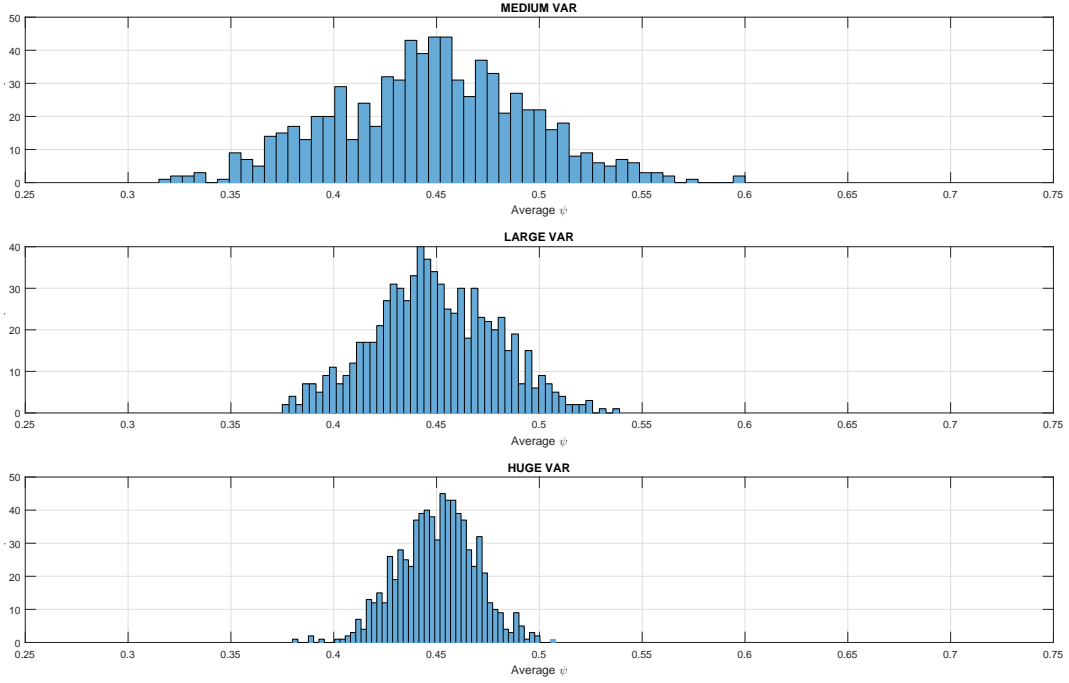


This figure displays the empirical distribution of the average number of rows of the random compression matrices Φ_i , $i = 1, \dots, n$ averaged across all n equations of the VAR, and according to the top 75% compressions, ranked in terms of the VAR overall BIC. For each of the n equations in the VAR, the model specification is

$$Y_{i,t} = \Theta_i^c \left(\Phi_i Z_t^i \right) + \sigma_i E_{i,t} \quad i = 1, \dots, n$$

where Z_t^i denotes the subset of the vector Z_t which applies to the i -th equation of the VAR: $Z_t^1 = (Y_{t-1})$, $Z_t^2 = (Y_{t-1}', -Y_{1,t})'$, $Z_t^3 = (Y_{t-1}', -Y_{1,t}, -Y_{2,t})'$, and so on. Similarly, Φ_i is a matrix with m rows and column dimension that conforms with Z_t^i .

Figure 2. Average sparsity (ψ) for top 75% compressions

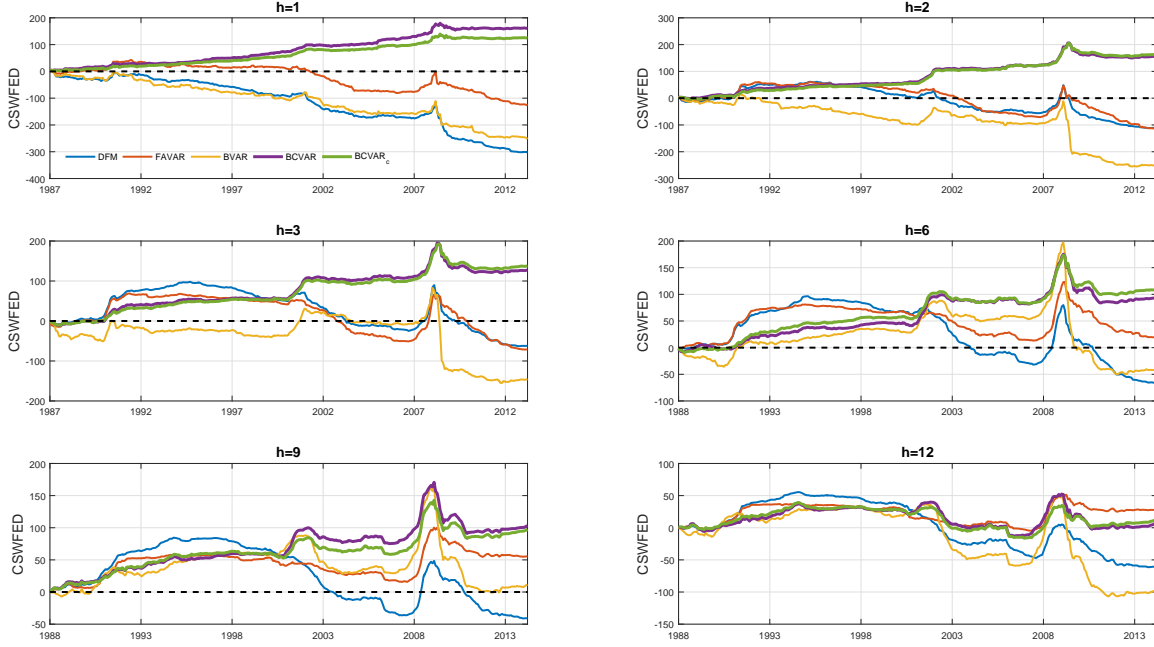


This figure displays the empirical distribution of the average sparsity factor ψ of the matrix Φ_i , $i = 1, \dots, n$, averaged across all n equations of the VAR, and according to the top 75% compressions, ranked in terms of the VAR overall BIC. For each of the n equations in the VAR, the model specification is

$$Y_{i,t} = \Theta_i^c \left(\Phi_i Z_t^i \right) + \sigma_i E_{i,t} \quad i = 1, \dots, n$$

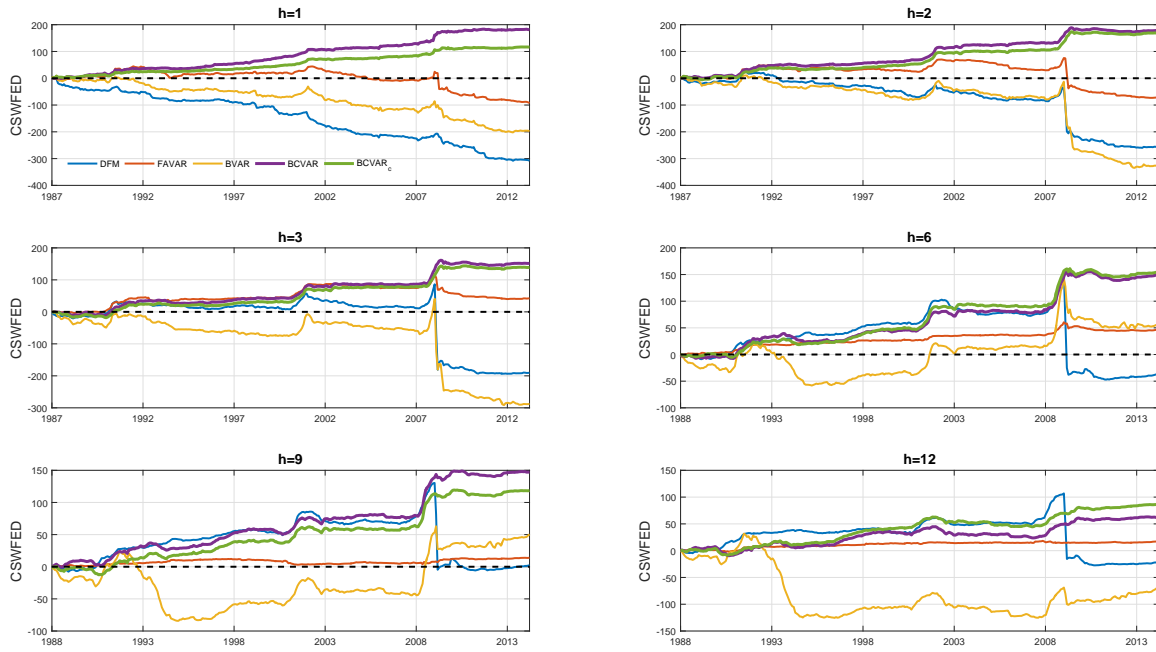
where Z_t^i denotes the subset of the vector Z_t which applies to the i -th equation of the VAR: $Z_t^1 = (Y_{t-1})$, $Z_t^2 = (Y_{t-1}', -Y_{1,t})'$, $Z_t^3 = (Y_{t-1}', -Y_{1,t}, -Y_{2,t})'$, and so on. Similarly, Φ_i is a matrix with m rows and column dimension that conforms with Z_t^i .

Figure 3. Cumulative sum of weighted forecast error differentials, Medium VAR



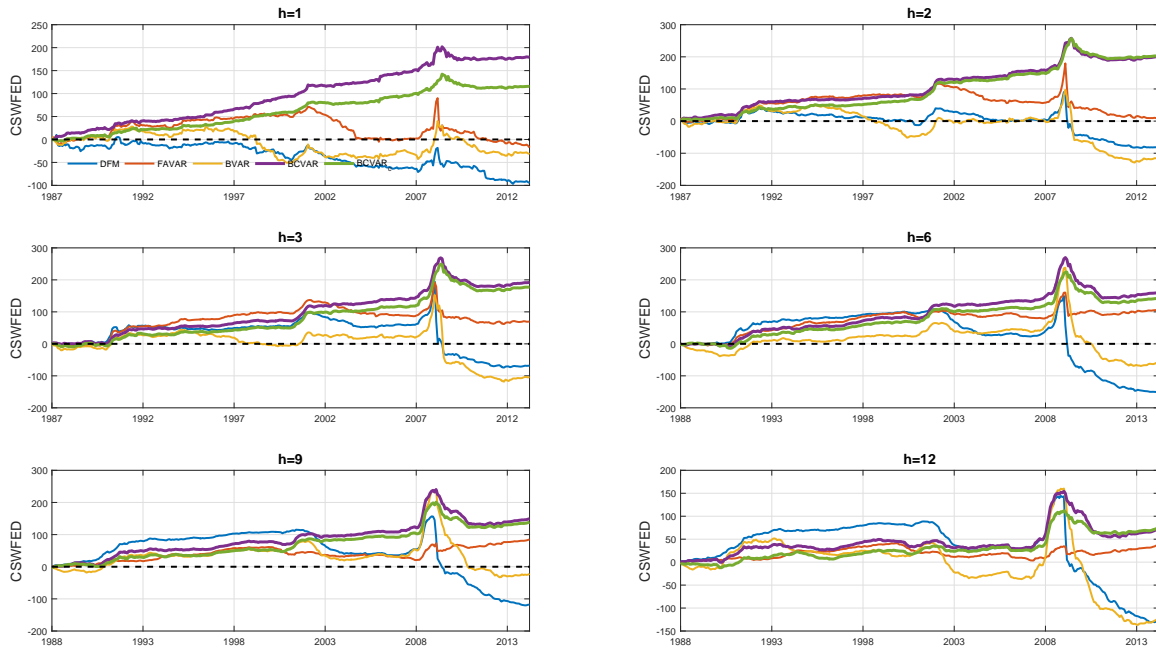
This figure plots the cumulative sum of weighted forecast errors generated by the AR(1) model minus the cumulative sum of weighted forecast errors generated by model i for a Medium size VAR. We define the weighted forecast error of model i and the AR(1) model at time $\tau + h$ as $we_{i,\tau+h} = (e'_{i,\tau+h} \times W \times e_{i,\tau+h})$ and $we_{bcmk,\tau+h} = (e'_{bcmk,\tau+h} \times W \times e_{bcmk,\tau+h})$, where $e_{i,\tau+h}$ and $e_{bcmk,\tau+h}$ are the $(N \times 1)$ vector of forecast errors, and W is an $(N \times N)$ matrix of weights. We set $N = 7$, to focus on the following key seven series, $\{PAYEMS, CPIAUCSL, FEDFUNDS, INDPRO, UNRATE, PPIFGS, GS10\}$. In addition, we set the matrix W to be a diagonal matrix featuring on the diagonal the inverse of the variances of the series to be forecast. \underline{t} and \bar{t} denote the start and end of the out-of-sample period, $i \in \{DFM, FAVAR, BVAR, BCVAR, BCVAR_e\}$, and $h \in \{1, 2, 3, 6, 9, 12\}$. All forecasts are generated out-of-sample using recursive estimates of the models, with the out of sample period starting in 1987:07 and ending in 2014:12. Each panel displays results for a different forecast horizon.

Figure 4. Cumulative sum of weighted forecast error differentials, Large VAR



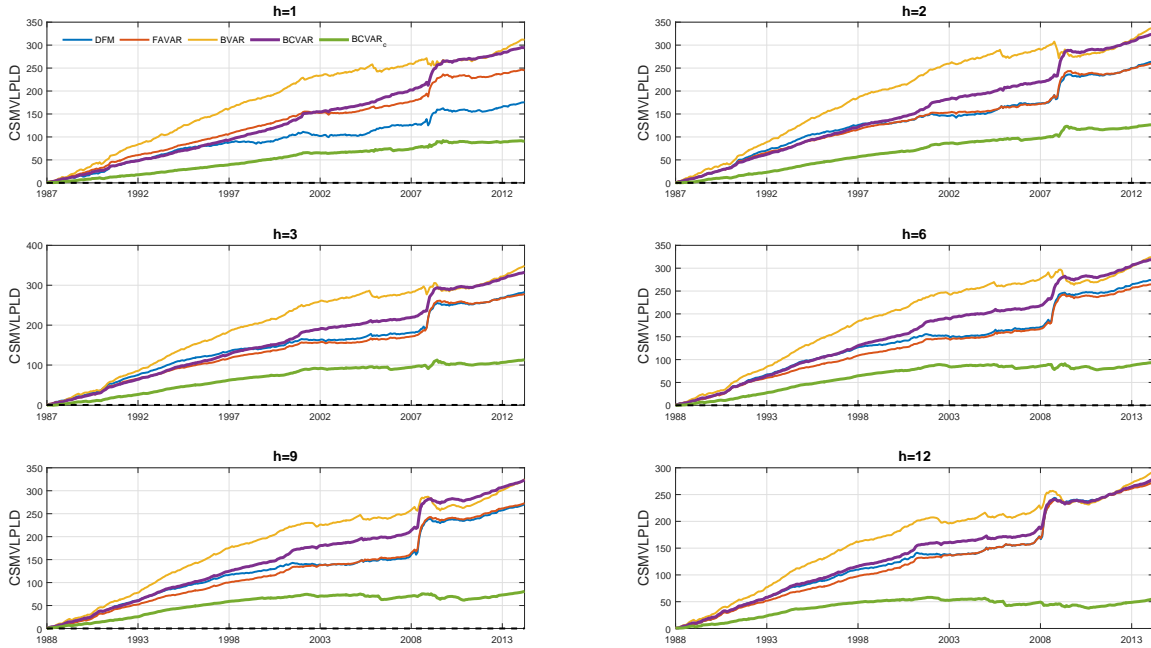
This figure plots the cumulative sum of weighted forecast errors generated by the AR(1) model minus the cumulative sum of weighted forecast errors generated by model i for a Large size VAR. $i \in \{DFM, FAVAR, BVAR, BCVAR, BCVAR_c\}$. See notes to [Figure 3](#) for additional details.

Figure 5. Cumulative sum of weighted forecast error differentials, Huge VAR



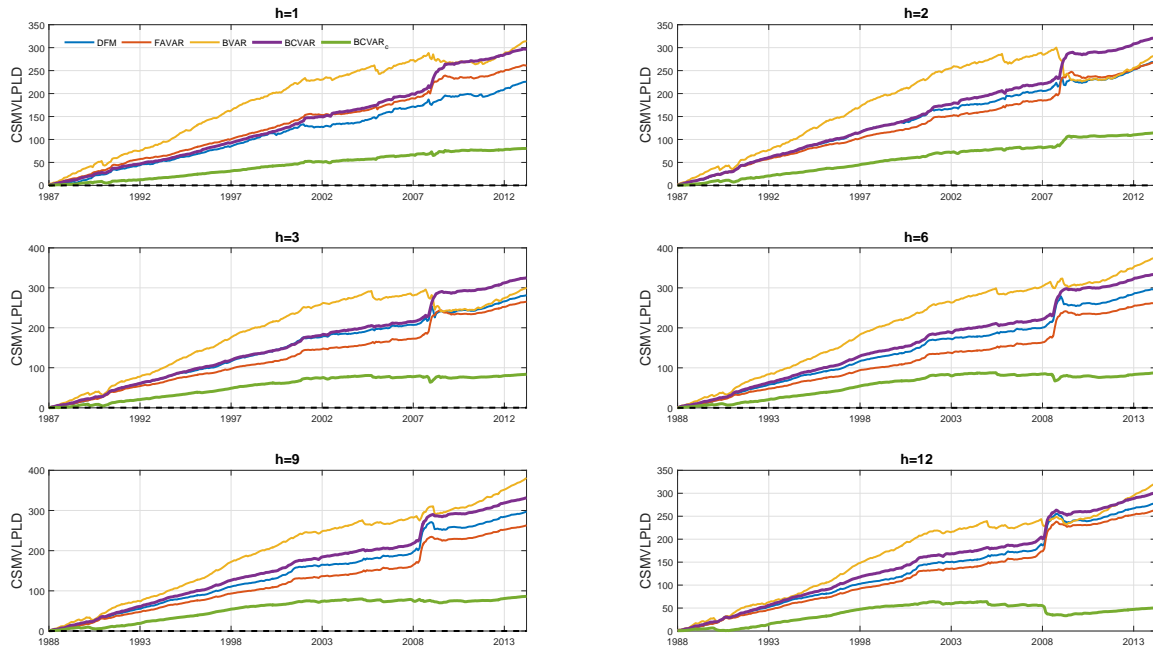
This figure plots the cumulative sum of weighted forecast errors generated by the AR(1) model minus the cumulative sum of weighted forecast errors generated by model i for a Huge size VAR. $i \in \{DFM, FAVAR, BVAR, BCVAR, BCVAR_c\}$. See notes to [Figure 3](#) for additional details.

Figure 6. Cumulative sum of multivariate log predictive likelihood differentials, Medium VAR



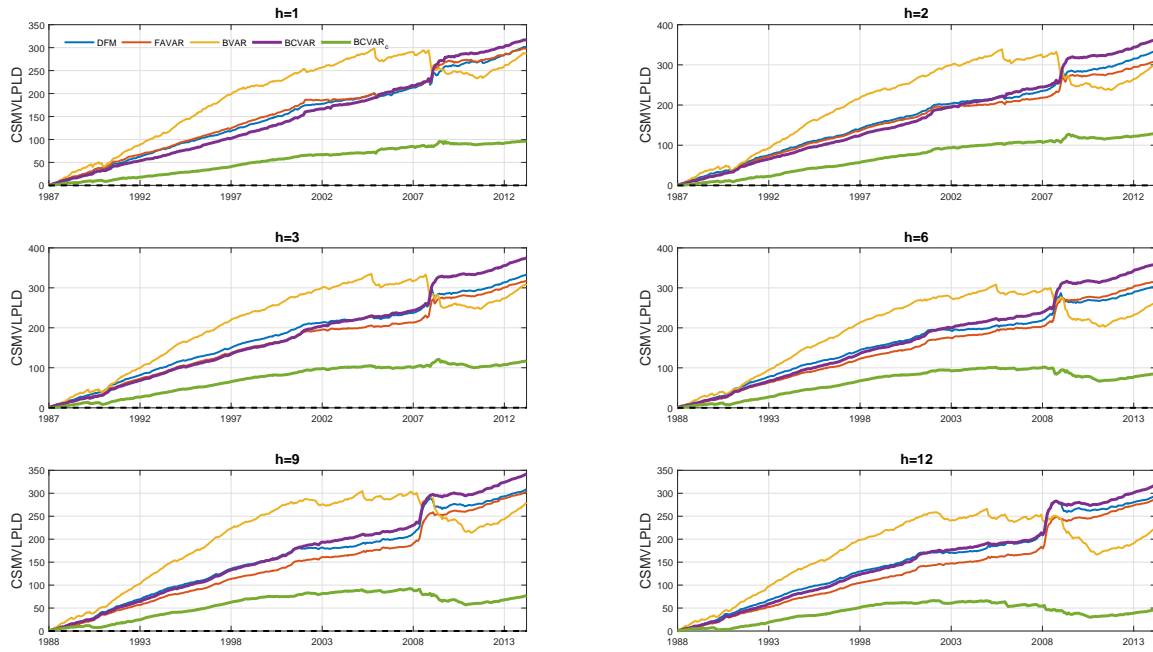
This figure plots the cumulative sum of the multivariate log predictive likelihoods generated by model i minus the cumulative sum of the multivariate log predictive likelihoods computed from an AR(1) model for a Medium size VAR. $i \in \{DFM, FAVAR, BVAR, BCVAR, BCVAR_c\}$, $h \in \{1, 2, 3, 6, 9, 12\}$, and the multivariate log predictive likelihoods are computed under the assumption of joint normality, as described in the text. All forecasts are generated out-of-sample using recursive estimates of the models, with the out of sample period starting in 1987:07 and ending in 2014:12. Each panel displays results for a different forecast horizon.

Figure 7. Cumulative sum of multivariate log predictive likelihood differentials, Large VAR



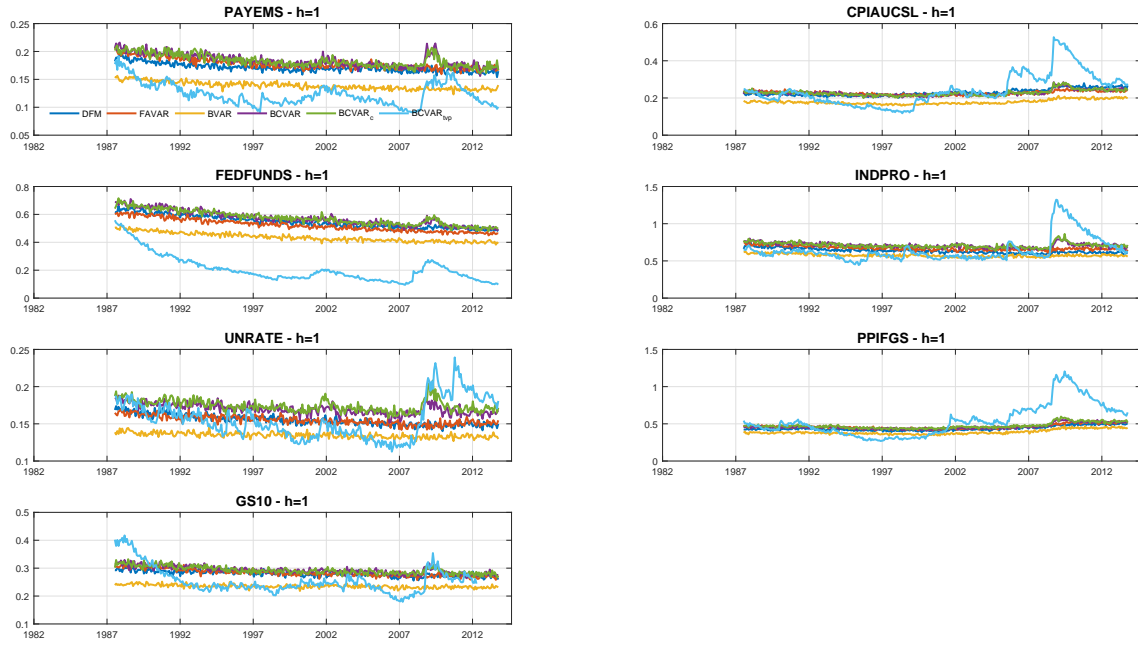
This figure plots the cumulative sum of the multivariate log predictive likelihoods generated by model i minus the cumulative sum of the multivariate log predictive likelihoods computed from an AR(1) model for a Large size VAR. $i \in \{DFM, FAVAR, BVAR, BCVAR, BCVAR_c\}$. See notes to Figure 6 for additional details.

Figure 8. Cumulative sum of multivariate log predictive likelihood differentials, Huge VAR



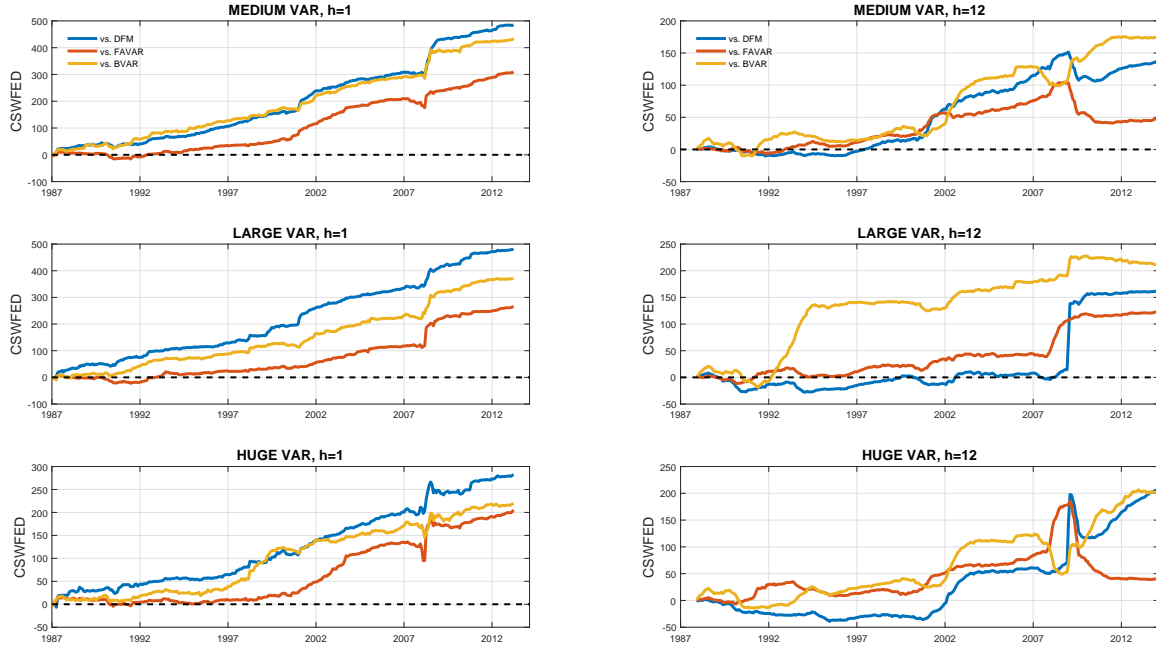
This figure plots the cumulative sum of the multivariate log predictive likelihoods generated by model i minus the cumulative sum of the multivariate log predictive likelihoods computed from an AR(1) model for a Huge size VAR. $i \in \{DFM, FAVAR, BVAR, BCVAR, BCVAR_c\}$. See notes to Figure 6 for additional details.

Figure 9. Predictive density volatilities, Medium VAR



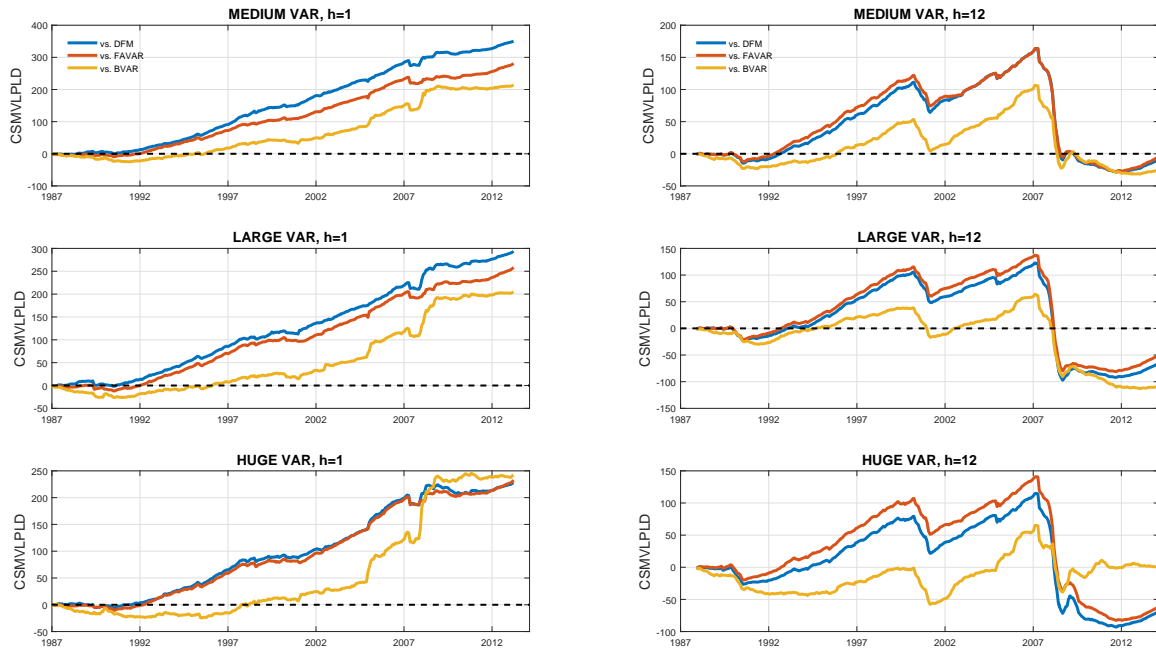
This figure plots the time series of the predicted volatilities over the entire out-of-sample period, for $h = 1$ and the different models entertained, $\{DFM, FAVAR, BVAR, BCVAR, BCVAR_c, BCVAR_{tv-psv}\}$. The out of sample period starts in 1987:07 and ends in 2014:12. Each panel displays results for a different variable j , where $j \in \{PAYEMS, CPIAUCSL, FEDFUNDS, INDPRO, UNRATE, PPIFGS, GS10\}$.

Figure 10. Cumulative sum of weighted forecast error differentials, Compressed TVP-SV VAR



This figure plots the cumulative sum of weighted forecast errors generated by either the DFM, FAVAR, or BVAR models minus the cumulative sum of weighted forecast errors generated by the $BCVAR_{tvp-sv}$ model for different VAR sizes and forecast horizons. We define the weighted forecast error of the $BCVAR_{tvp-sv}$ model and model i alternative at time $\tau + h$ as $we_{\tau+h} = (e'_{\tau+h} \times W \times e_{\tau+h})$ and $we_{i,\tau+h} = (e'_{i,\tau+h} \times W \times e_{i,\tau+h})$, where $e_{\tau+h}$ and $e_{i,\tau+h}$ are the $(N \times 1)$ vector of forecast errors, and W is an $(N \times N)$ matrix of weights. We set $N = 7$, to focus on the following key seven series, $\{PAYEMS, CPIAUCSL, FEDFUNDS, INDPRO, UNRATE, PPIFGS, GS10\}$. In addition, we set the matrix W to be a diagonal matrix featuring on the diagonal the inverse of the variances of the series to be forecast. h denotes the forecast horizon, with $h \in \{1, 12\}$. All forecasts are generated out-of-sample using recursive estimates of the models, with the out of sample period starting in 1987:07 and ending in 2014:12.

Figure 11. Cumulative sum of multivariate log predictive likelihood differentials, Compressed TVP-SV VAR



This figure plots the cumulative sum of the multivariate log predictive likelihoods generated by the $BCVAR_{tvp-sv}$ model minus the cumulative sum of the multivariate log predictive likelihoods computed from either the DFM, FAVAR, or BVAR model for different VAR sizes and forecast horizons. The multivariate log predictive likelihoods are computed under the assumption of joint normality, as described in the text. All forecasts are generated out-of-sample using recursive estimates of the models, with the out of sample period starting in 1987:07 and ending in 2014:12.

Appendix A Data and transformations

The column Tcode denotes the following data transformation for a series x : (1) no transformation; (2) Δx_t ; (3) $\Delta^2 x_t$; (4) $\log(x_t)$; (5) $\Delta \log(x_t)$; (6) $\Delta^2 \log(x_t)$. The FRED column gives mnemonics in FRED followed by a short description. The comparable series description in Global Insight is given in the column GSI:Description.

Table A.1. **Output and Income**

| <i>Series id</i> | <i>Tcode</i> | <i>Medium</i> | <i>Large</i> | <i>FRED</i> | <i>Description</i> | <i>GSI:Description</i> |
|------------------|--------------|---------------|--------------|---------------|-------------------------------------|------------------------|
| 1 | 5 | X | X | RPI | Real Personal Income | PI |
| 2 | 5 | | X | W875RX1 | RPI ex. Transfers | PI less transfers |
| 6 | 5 | X | X | INDPRO | IP Index | IP: total |
| 7 | 5 | | | IPFPNSS | IP: Final Products and Supplies | IP: products |
| 8 | 5 | | | IPFINAL | IP: Final Products | IP: final prod |
| 9 | 5 | | | IPCONGD | IP: Consumer Goods | IP: cons gds |
| 10 | 5 | | | IPDCONGD | IP: Durable Consumer Goods | IP: cons dble |
| 11 | 5 | | | IPNCONGD | IP: Nondurable Consumer Goods | IP: cons nondble |
| 12 | 5 | | | IPBUSEQ | IP: Business Equipment | IP: bus eqpt |
| 13 | 5 | | | IPMAT | IP: Materials | IP: matls |
| 14 | 5 | | | IPDMAT | IP: Durable Materials | IP: dble matls |
| 15 | 5 | | | IPNMAT | IP: Nondurable Materials | IP: nondble matls |
| 16 | 5 | | | IPMANSICS | IP: Manufacturing | IP: mfg |
| 17 | 5 | | | IPB51222S | IP: Residential Utilities | IP: res util |
| 18 | 5 | | | IPFUELS | IP: Fuels | IP: fuels |
| 19 | 1 | | X | NAPMPI | ISM Manufacturing: Production | NAPM prodn |
| 20 | 1 | | | CAPUTLB00004S | Capacity Utilization: Manufacturing | Cap util |

Table A.2. **Labor Market**

| <i>Series id</i> | <i>Tcode</i> | <i>Medium</i> | <i>Large</i> | <i>FRED</i> | <i>Description</i> | <i>GSI:Description</i> |
|------------------|--------------|---------------|--------------|---------------|-------------------------------------|------------------------|
| 21 | 1 | X | X | HWI | Help-Wanted Index for US | Help wanted indx |
| 22 | 1 | | X | HWIURATIO | Help Wanted to Unemployed ratio | Help wanted/unemp |
| 23 | 5 | | X | CLF16OV | Civilian Labor Force | Emp CPS total |
| 24 | 5 | | | CE16OV | Civilian Employment | Emp CPS nonag |
| 25 | 2 | X | X | UNRATE | Civilian Unemployment Rate | U: all |
| 26 | 1 | | | UEMPMEAN | Average Duration of Unemployment | U: mean duration |
| 27 | 5 | | | UEMPLT5 | Civilians Unemployed ≤ 5 Weeks | U ≤ 5 wks |
| 28 | 5 | | | UEMP5TO14 | Civilians Unemployed 5-14 Weeks | U 5-14 wks |
| 29 | 5 | | | UEMP15OV | Civilians Unemployed > 15 Weeks | U > 15 wks |
| 30 | 5 | | | UEMP15T26 | Civilians Unemployed 15-26 Weeks | U 15-26 wks |
| 31 | 5 | | | UEMP27OV | Civilians Unemployed > 27 Weeks | U > 27 wks |
| 32 | 5 | | | CLAIMSx | Initial Claims | UI claims |
| 33 | 5 | X | X | PAYEMS | All Employees: Total nonfarm | Emp: total |
| 34 | 5 | | | USGOOD | All Employees: Goods-Producing | Emp: gds prod |
| 35 | 5 | | | CES1021000001 | All Employees: Mining and Logging | Emp: mining |
| 36 | 5 | | | USCONS | All Employees: Construction | Emp: const |
| 37 | 5 | | | MANEMP | All Employees: Manufacturing | Emp: mfg |
| 38 | 5 | | | DMANEMP | All Employees: Durable goods | Emp: dble gds |
| 39 | 5 | | | NDMANEMP | All Employees: Nondurable goods | Emp: nondbles |
| 40 | 5 | | | SRVPRD | All Employees: Service Industries | Emp: services |
| 41 | 5 | | | USTPU | All Employees: TT&U | Emp: TTU |
| 42 | 5 | | | USWTRADE | All Employees: Wholesale Trade | Emp: wholesale |
| 43 | 5 | | | USTRADE | All Employees: Retail Trade | Emp: retail |
| 44 | 5 | | | USFIRE | All Employees: Financial Activities | Emp: FIRE |
| 45 | 5 | | | USGOVT | All Employees: Government | Emp: Govt |
| 46 | 1 | | X | CES0600000007 | Hours: Goods-Producing | Avg hrs |
| 47 | 1 | | | AWOTMAN | Overtime Hours: Manufacturing | Overtime: mfg |
| 48 | 1 | | | AWHMAN | Hours: Manufacturing | Avg hrs: mfg |
| 49 | 1 | | | NAPMEI | ISM Manufacturing: Employment | NAPM empl |
| 128 | 5 | | | CES0600000008 | Ave. Hourly Earnings: Goods | AHE: goods |
| 129 | 5 | | | CES2000000008 | Ave. Hourly Earnings: Construction | AHE: const |
| 130 | 5 | | | CES3000000008 | Ave. Hourly Earnings: Manufacturing | AHE: mfg |

Table A.3. **Housing**

| <i>Series id</i> | <i>Tcode</i> | <i>Medium</i> | <i>Large</i> | <i>FRED</i> | <i>Description</i> | <i>GSI:Description</i> |
|------------------|--------------|---------------|--------------|-------------|--------------------|------------------------|
| 50 | 4 | X | | HOUST | Starts: Total | Starts: nonfarm |
| 51 | 4 | | | HOUSTNE | Starts: Northeast | Starts: NE |
| 52 | 4 | | | HOUSTMW | Starts: Midwest | Starts: MW |
| 53 | 4 | | | HOUSTS | Starts: South | Starts: South |
| 54 | 4 | | | HOUSTW | Starts: West | Starts: West |
| 55 | 4 | X | | PERMIT | Permits | BP: total |
| 56 | 4 | | | PERMITNE | Permits: Northeast | BP: NE |
| 57 | 4 | | | PERMITMW | Permits: Midwest | BP: MW |
| 58 | 4 | | | PERMITS | Permits: South | BP: South |
| 59 | 4 | | | PERMITW | Permits: West | BP: West |

Table A.4. Consumption, Orders and Inventories

| <i>Series id</i> | <i>Tcode</i> | <i>Medium</i> | <i>Large</i> | <i>FRED</i> | <i>Description</i> | <i>GSI:Description</i> |
|------------------|--------------|---------------|--------------|-----------------|--------------------------------|------------------------|
| 3 | 5 | | X | DPCERA3M086SBEA | Real PCE | Real Consumption |
| 4 | 5 | | X | CMRMTSPLx | Real M&T Sales | M&T sales |
| 5 | 5 | | X | RETAILx | Retail and Food Services Sales | Retail sales |
| 60 | 1 | X | | NAPM | ISM: PMI Composite Index | PMI |
| 61 | 1 | | X | NAPMNOI | ISM: New Orders Index | NAPM new ordrs |
| 62 | 1 | | X | NAPMSDI | ISM: Supplier Deliveries Index | NAPM vendor del |
| 63 | 1 | | X | NAPMII | ISM: Inventories Index | NAPM Invent |
| 65 | 5 | | | AMDMNOx | Orders: Durable Goods | Orders: dble gds |
| 67 | 5 | | | AMDMUOx | Unfilled Orders: Durable Goods | Unf orders: dble |
| 68 | 5 | | | BUSINVx | Total Business Inventories | M&T invent |
| 69 | 1 | | | ISRATIOx | Inventories to Sales Ratio | M&T invent/sales |

Table A.5. Money and Credit

| <i>Series id</i> | <i>Tcode</i> | <i>Medium</i> | <i>Large</i> | <i>FRED</i> | <i>Description</i> | <i>GSI:Description</i> |
|------------------|--------------|---------------|--------------|-------------|----------------------------------|------------------------|
| 70 | 5 | X | X | M1SL | M1 Money Stock | M1 |
| 71 | 5 | | X | M2SL | M2 Money Stock | M2 |
| 73 | 5 | | X | M2REAL | Real M2 Money Stock | M2 (real) |
| 74 | 5 | | X | AMBSL | St. Louis Adjusted Monetary Base | MB |
| 75 | 5 | | X | TOTRESNS | Total Reserves | Reserves tot |
| 77 | 5 | X | X | BUSLOANS | Commercial and Industrial Loans | C&I loan plus |
| 78 | 5 | | | REALLN | Real Estate Loans | DC&I loans |
| 79 | 5 | | X | NONREVSL | Total Nonrevolving Credit | Cons credit |
| 80 | 1 | | X | CONSPI | Credit to PI ratio | Inst cred/PI |
| 132 | 5 | | | MZMSL | MZM Money Stock | N.A. |
| 133 | 5 | | | DTCOLNVHFNM | Consumer Motor Vehicle Loans | N.A. |
| 134 | 5 | | | DTCTHFNM | Total Consumer Loans and Leases | N.A. |
| 135 | 5 | X | | INVEST | Securities in Bank Credit | N.A. |

Table A.6. Interest rates and Exchange rates

| <i>Series id</i> | <i>Tcode</i> | <i>Medium</i> | <i>Large</i> | <i>FRED</i> | <i>Description</i> | <i>GSI:Description</i> |
|------------------|--------------|---------------|--------------|-------------|------------------------------|------------------------|
| 85 | 2 | X | X | FEDFUNDS | Effective Federal Funds Rate | Fed Funds |
| 86 | 2 | | X | CP3M | 3-Month AA Comm. Paper Rate | Comm paper |
| 87 | 2 | | X | TB3MS | 3-Month T-bill | 3 mo T-bill |
| 88 | 2 | | X | TB6MS | 6-Month T-bill | 6 mo T-bill |
| 89 | 2 | | X | GS1 | 1-Year T-bond | 1 yr T-bond |
| 90 | 2 | | X | GS5 | 5-Year T-bond | 5 yr T-bond |
| 91 | 2 | X | X | GS10 | 10-Year T-bond | 10 yr T-bond |
| 92 | 2 | | X | AAA | Aaa Corporate Bond Yield | Aaa bond |
| 93 | 2 | | X | BAA | Baa Corporate Bond Yield | Baa bond |
| 94 | 1 | | | COMPAPFF | CP - FFR spread | CP-FF spread |
| 95 | 1 | | | TB3SMFFM | 3 Mo. - FFR spread | 3 mo-FF spread |
| 96 | 1 | | | TB6SMFFM | 6 Mo. - FFR spread | 6 mo-FF spread |
| 97 | 1 | | | T1YFFM | 1 yr. - FFR spread | 1 yr-FF spread |
| 98 | 1 | | | T5YFFM | 5 yr. - FFR spread | 5 yr-FF spread |
| 99 | 1 | X | | T10YFFM | 10 yr. - FFR spread | 10 yr-FF spread |
| 100 | 1 | | | AAAFFM | Aaa - FFR spread | Aaa-FF spread |
| 101 | 1 | | | BAAFFM | Baa - FFR spread | Baa-FF spread |
| 103 | 5 | | X | EXSZUS | Switzerland / U.S. FX Rate | Ex rate: Switz |
| 104 | 5 | | X | EXJPUS | Japan / U.S. FX Rate | Ex rate: Japan |
| 105 | 5 | X | X | EXUSUK | U.S. / U.K. FX Rate | Ex rate: UK |
| 106 | 5 | | X | EXCAUS | Canada / U.S. FX Rate | EX rate: Canada |

Table A.7. **Prices**

| <i>Series id</i> | <i>Tcode</i> | <i>Medium</i> | <i>Large</i> | <i>FRED</i> | <i>Description</i> | <i>GSI:Description</i> |
|------------------|--------------|---------------|--------------|-----------------|----------------------------------|------------------------|
| 107 | 5 | X | X | PPIFGS | PPI: Finished Goods | PPI: fin gds |
| 108 | 5 | | X | PPIFCG | PPI: Finished Consumer Goods | PPI: cons gds |
| 109 | 5 | | X | PPIITM | PPI: Intermediate Materials | PPI: int materials |
| 110 | 5 | | X | PPICRM | PPI: Crude Materials | PPI: crude materials |
| 111 | 5 | X | | oilprice | Crude Oil Prices: WTI | Spot market price |
| 112 | 5 | | | PPICMM | PPI: Commodities | PPI: nonferrous |
| 113 | 1 | | | NAPMPRI | ISM Manufacturing: Prices | NAPM com price |
| 114 | 5 | X | X | CPIAUCSL | CPI: All Items | CPI-U: all |
| 115 | 5 | | | CPIAPPSL | CPI: Apparel | CPI-U: apparel |
| 116 | 5 | | | CPITRNSL | CPI: Transportation | CPI-U: transp |
| 117 | 5 | | | CPIMEDSL | CPI: Medical Care | CPI-U: medical |
| 118 | 5 | | | CUSR0000SAC | CPI: Commodities | CPI-U: comm. |
| 119 | 5 | | | CUUR0000SAD | CPI: Durables | CPI-U: dbles |
| 120 | 5 | | | CUSR0000SAS | CPI: Services | CPI-U: services |
| 121 | 5 | | | CPIULFSL | CPI: All Items Less Food | CPI-U: ex food |
| 122 | 5 | | | CUUR0000SA0L2 | CPI: All items less shelter | CPI-U: ex shelter |
| 123 | 5 | | | CUSR0000SA0L5 | CPI: All items less medical care | CPI-U: ex med |
| 124 | 5 | | | PCEPI | PCE: Chain-type Price Index | PCE defl |
| 125 | 5 | | | DDURRG3M086SBEA | PCE: Durable goods | PCE defl: dlbes |
| 126 | 5 | | | DNDGRG3M086SBEA | PCE: Nondurable goods | PCE defl: nondble |
| 127 | 5 | | | DSERRG3M086SBEA | PCE: Services | PCE defl: service |

Table A.8. **Stock Market**

| <i>Series id</i> | <i>Tcode</i> | <i>Medium</i> | <i>Large</i> | <i>FRED</i> | <i>Description</i> | <i>GSI:Description</i> |
|------------------|--------------|---------------|--------------|---------------|---------------------------|------------------------|
| 81 | 5 | X | X | S&P 500 | S&P: Composite | S&P 500 |
| 82 | 5 | | X | S&P: indust | S&P: Industrials | S&P: indust |
| 83 | 1 | | X | S&P div yield | S&P: Dividend Yield | S&P div yield |
| 84 | 5 | | X | S&P PE ratio | S&P: Price-Earnings Ratio | S&P PE ratio |